STATE OF ILLINOIS
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MINERALOGY OF GLACIAL TILLS AND THEIR WEATHERING PROFILES IN ILLINOIS

Part II. Weathering Profiles

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ABSTRACT

Part I of this study (Circular 347) reported the mineral compositions of unaltered glacial tills in Illinois. Part II considers the mineral composition of buried weathering profiles developed in the upper part of the glacial tills and the changes effected by weathering in the pebble, sand, silt, and clay fractions. Grain-size and mineral analyses were made of 26 bulk samples from 6 localities, and X-ray diffraction analyses were made of 140 samples from 12 localities. Grain size is used in evaluating the degree of uniformity in the deposit prior to weathering. In the in-situ profiles, vertical grain-size variations result from solution of carbonates, clay eluviation and illuviation, disaggregation, and decomposition of silicate minerals. A sharp discontinuity in grain size and mineral composition characterizes the base of the accretion-gley. The clay minerals in the in-situ profiles display a gradational upward sequence of alterations from the unaltered till, characterized by a progressive increase in expandable clay minerals and, in the B-zone, by the prominence of heterogeneous swelling material. In the accretion-gley profiles, a sharp discontinuity in clay-mineral composition occurs at the base of the accretion-gley, and pedogenic processes have produced vermiculite and homogeneous swelling montmorillonite in the accretion-gley. Illite alteration extends downward into the CL-zone in Yarmouth and Sangamon Soils, and into the B_2-zone in soils on Altonian tills; it has not been detected in the B-zone of soils on Woodfordian tills. In the pebble and sand fractions, 39 categories of rocks and minerals are differentiated and show a wide range of weathering resistance in these profiles. Only the carbonate minerals and shale are entirely lacking in the B-zones and accretion-gleys. Some rocks and minerals are so stable that no depletion can be detected; therefore, less stable rocks and minerals are most useful in evaluating degree of profile development, particularly hornblende (low stability), garnet (medium), and epidote (high). In in-situ profiles, percentage loss of silicate minerals from the pebble and sand fractions is quite small upward through the B-zones, and decomposition of silicate minerals occurs primarily at the top of the profile. In accretion-gley profiles, the mineralogical change is more abrupt at the base of the accretion-gley, reflecting the source of the material from the weathered adjacent slopes, but compositional variations are erratic throughout the accretion-gley. The accretion-gleys show no greater depletion of silicate minerals than do the B-zones. Most of the material called gumbotil is a sediment—accretion-gley. The early definitions of gumbotil stipulated that it is a product of mineral decomposition in place, and therefore the term is inappropriate.

INTRODUCTION

Deposits derived directly or indirectly as a product of continental glaciation constitute the materials at and immediately below the surface of much of Illinois. Because these deposits are of direct concern in construction activities, questions of land use, development of ground-water supplies, as raw materials for ceramic manufacture, and as the parent materials of soils, the Illinois Geological Survey has carried on a program to study their mineral composition. The present report describes the composition of the weathering profiles that developed on the surfaces of the till sheets prior to their burial by younger deposits and thus completes the study started in Circular 347 (Willman, Glass, and Frye, 1963).

Since the closing decades of the last century, the importance of deposits that are now called accretion-gleys and of buried in-situ soil profiles to the stratigraphy of the Pleistocene deposits in Iowa (McGee, 1878; Bain, 1897) and in Illinois (Chamberlin, 1895; Leverett, 1899) has been recognized. Although during this century the interpretation of the buried in-situ profiles has evolved along lines parallel to the interpretation of surface soils (Ruhe, 1965; Thorp, 1965), the materials of the accretion-gleys have been considered to represent a special product of weathering effects on glacial till. In 1916 Kay coined the term "gumbotil" for weathered materials on pre-Wisconsinan tills, and four years later Kay and Pearce (1920) described these materials in more detail, attributing them to an extreme degree of chemical decomposition of till in place. Gumbotil in Iowa was further described by Kay and Apfel (1929). In Illinois, Leighton and MacClintock (1930) restricted gumbotil to the materials that are now called accretion-gley, and they introduced the terms "siltil" and "mesotil" for well-drained and medium-drained in-situ soil profiles. Since the introduction of the gumbotil hypothesis, opposing views have been presented (Keyes, 1922; Hobbs, 1945; Krusekopf, 1948; Hseung, Marshall, and Krusekopf, 1950; Frye, Shaffer, Willman, and Ekblaw, 1960). It has been pointed out that some soils on till plains are in part sediments (Ruhe, 1956) and that some materials which have been called gumbotil also are deposits on the till (Frye and Leonard, 1952). Mineralogical data and field evidence have been presented to show that the materials called gumbotil are accretion-gley (Frye, Willman, and Glass, 1960).

In this study of the mineralogy of buried weathering profiles on tills, we have not attempted uniform geographic coverage of the state but have selected typical examples of the several major soil-stratigraphic units for detailed study. In order to evaluate the size fractions coarser than sand, samples that weighed approximately 50 pounds each were taken at six localities; thus, meaningful analyses could be made of materials as coarse as the 16 to 32 mm. size grade. Of the six localities, four are from Sangamon Soil (two each from in-situ profiles and accretion-gleys), and two are from Yarmouth Soil (one each from an in-situ profile and an accretion-gley). Rock and mineral identifications were made by microscopic methods for the sand and pebble fractions and by X-ray diffraction for the less than .002 mm size fraction of the clay. X-ray diffraction analyses were made of samples from six additional profiles; three Sangamon accretion-gley profiles, one Sangamon in-situ profile, one in-situ profile in till of Altonian age, and one Sangamon in-situ profile developed in Pennsylvanian shale. The locations of the 12 sections are shown in figure 1, and the descriptions of the sections are given at the end of the report. The descriptions, in addition to giving the stratigraphic succession at each locality, show the stratigraphic position of each sample listed in the tables.

In addition to describing the mineral composition of the zones of the profiles and of the subjacent till, the mineral composition data are used as a basis for interpreting the origin of the weathering profiles. An earlier study was made of

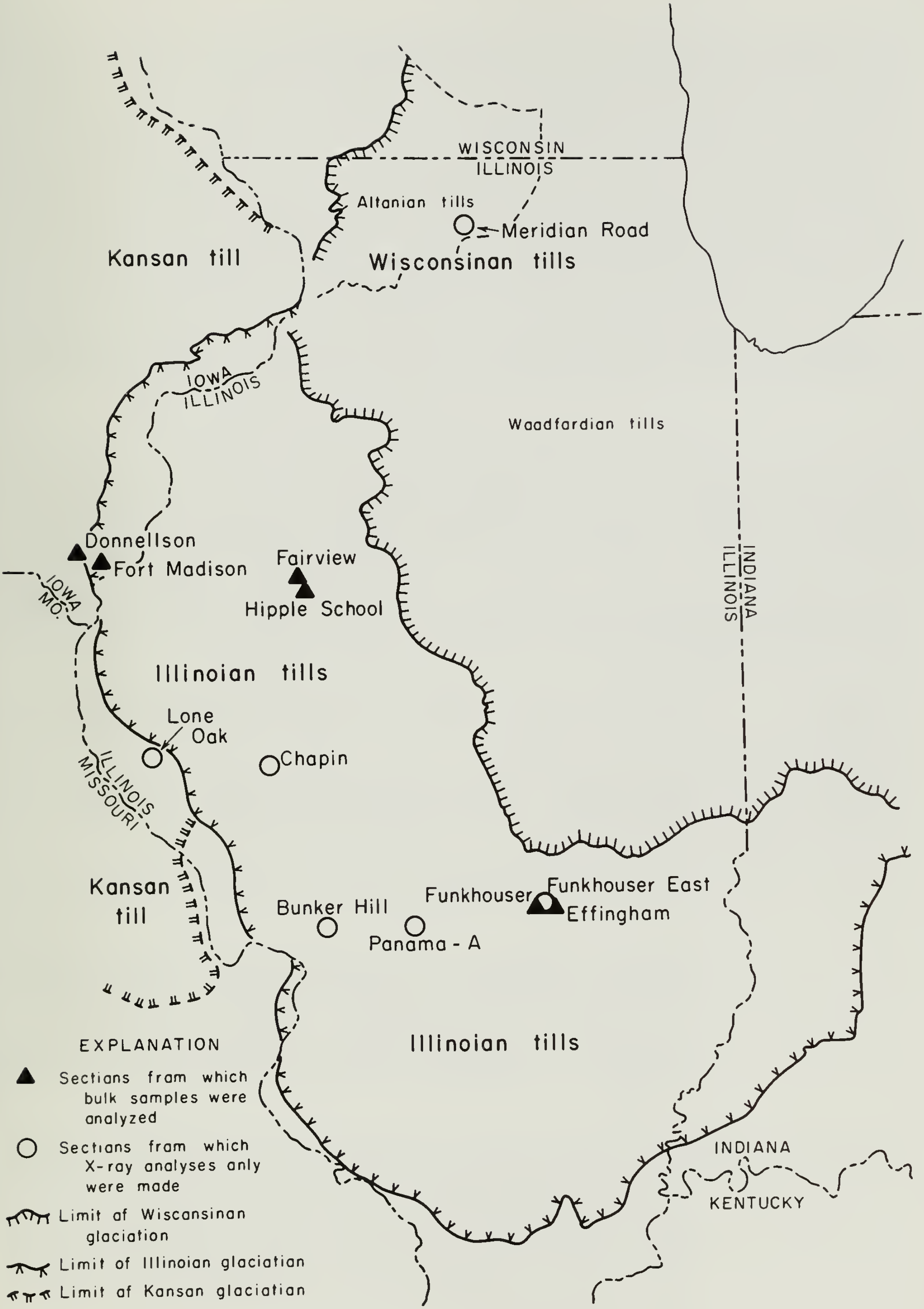

Figure 1. Location of sections described and limits of glacial advances.

the mineral composition of the matrix (.250 mm and smaller diameter particles) of the buried soils on the tills in Illinois (Frye, Willman, and Glass, 1960), and the present study is an extension of the earlier report, as well as Part II of "Mineralogy of Glacial Tills and Their Weathering Profiles". Analyses of more than 350 samples were given in the two previous reports, and analyses of 140 additional samples are given in this report. However, analyses of size fractions coarser than .250 mm were made only for the 26 bulk samples from six localities. The following analyses were made: size analyses (table 1); rock and mineral analyses of the 2, 4, 8, and 16mm fractions (table 3); light-mineral analyses of the .062, .125, .250, and .500mm fractions (table 4); heavy-mineral analyses of the .062, .125, and .250mm fractions (table 4); and clay-mineral analyses of the minus .002mm fraction (table 2). Clay-mineral analyses were made of spot samples, interspersed with the bulk samples, in order to give a more continuous sequence through the profiles. Tables 1 to 4 are at the end of the report. Grain-size nomenclature conforms to the National Research Council (1947) classification.

Terminology used for Buried Weathering Profiles

In our earlier report (Frye, Willman, and Glass, 1960), in order to discuss the position of samples within a profile of weathering, the several zone designations are defined. In the present report, the zone designations are essentially the same; therefore, basic data presented in these two reports may be used similarly. A new term GB-zone is defined. Definitions of the several zones as used for buried weathering profiles in this report are given below. Where terminology is referred to standard pedologic nomenclature, the Soil Survey Manual is followed (U. S. Department of Agriculture, 1951).

In-situ profile = Weathering profile developed vertically without horizontal transport displaying the units of a normal or zonal soil profile.

Accretion-gley = Soil material that slowly accumulated in a gleying environment—the G-zone, a product of horizontal transport. A profile containing accretion-gley is called an accretion-gley profile.

A-zone = The A-horizon, with subdivisions of A_1, A_2, and A_3, of standard pedologic terminology.

B-zone = The B-horizon, with subdivisions of B_1, B_2, and B_3, of standard pedologic terminology. Commonly oxidized to some shade of red-brown, brown, or gray-brown; commonly contains clay-skins, hydrous iron oxides, Mn-Fe pellets, limonite streaks or mottling, and displays some type of soil structure except where obliterated by post-burial processes. It is the zone of clay enrichment.

BG-zone = A gleyed B-zone. Locally it occurs in the position of the B-zone of an in-situ profile where drainage is poor and where a mildly reducing environment has produced some shade of gray or mottling of gray on brown; in such situations, it displays many of the characteristics of a B-zone. In some places, a BG-zone may occur as a relatively thin, altered zone below accretion-gley; in such a situation, it lacks soil structure and prominent clay accumulation.

G-zone = Accretion-gley. A deposit produced by slow, incremental accumulation of predominantly fine-textured material characterized by an abundance of clay, derived by wash from adjacent low gradient slopes of the microtopography, with or without added increments of loess, and accumulated in a poorly drained situation that was wet or intermittently wet in the presence of sufficient organic matter to produce an acid and reducing environment. Pedogenesis of clay minerals generally occurs in this environment. Some organic material may be preserved, soil structure and goethite are generally absent, and indistinct bedding may be observed in places. The color is always some shade of gray except where secondarily oxidized.

GB-zone = A secondarily developed B-zone in the top of a deposit of accretion-gley, oxidized, displays soil structure, tan to brown, commonly mottled gray.

C-zone = The C-horizon of standard pedologic terminology. Weathered parent material that generally occurs immediately below the B-zone, but it may be below an A-, BG-, or G-zone. In areas where the parent material was initially calcareous, the C-zone is divided into a CL-zone and a CC-zone.

CL-zone = Leached C-zone. The zone immediately below a B-zone, BG-zone, or G-zone in which the matrix is leached of primary calcite and dolomite; it is strongly to weakly oxidized, but it does not display soil structure or clay accumulation.

CC-zone = The part of the C-zone immediately below the CL-zone, containing in the matrix detectable amounts of calcite and/or dolomite. It is oxidized and displays the structure of the parent material. At the top of the CC-zone in many deeply developed profiles is a subzone from which calcite has been leached but which retains dolomite. In some profiles, secondary calcium carbonate has accumulated near the top of CC-zone and is designated a Cca-zone.

Unaltered till = The material below the CC-zone that displays no evidence, on field examination, of oxidation or alteration by weathering; joints that extend below the profile may display oxidized zones, or rinds, adjacent to the joint surface. In some situations, laboratory analysis reveals clay-mineral alteration extending downward into this zone.

To assist the reader of this report in placing the various profiles of weathering in their proper stratigraphic context, the following tabulation is given. It lists only the stratigraphic units referred to in this report and is not a complete listing of stratigraphic units for the Pleistocene of Illinois. For a discussion of the stratigraphy of glacial tills and their mineralogy in Illinois, see Willman, Glass, and Frye, (1963) and Frye, Willman, and Black, (1965).

STRATIGRAPHIC TERMS USED IN THIS REPORT

STAGE	SUBSTAGE	UNITS OF PHYSCIAL STRATIGRAPHY	
WISCONSINAN	VALDERAN		
	TWOCREEKAN	Peoria Loess	Richland Loess
			Shelbyville till
	WOODFORDIAN		Morton Loess
	FARMDALIAN	Farmdale [redacted] silt and peat	
	ALTONIAN	Winnebago tills	Roxana Silt
			Zone IV
			Zone III
			Zone II
			Zone Ib
			Zone Ia
SANGAMONIAN		Sangamon Soil; accretion-gley	
ILLINOIAN	BUFFALO HART	Buffalo Hart till	
	JACKSONVILLE	Jacksonville till	
	LIMAN	Mendon till	
YARMOUTHIAN		Yarmouth Soil; accretion-gley	
KANSAN			
AFTONIAN		Afton Soil; accretion-gley	
NEBRASKAN			

Laboratory Methods

The 26 bulk samples averaged 50 pounds dry weight, ranging from 30 to 62 pounds. They were air dried, and the entire sample was screened dry through a 2mm screen. The plus 2mm material was wet screened through screens with openings of 32, 16, 8, 4, and 2mm. In this and in the following steps of the mechanical analysis, aggregates formed by the bonding effect of clay were broken down by gentle abrasion on the screens. Repeated checking with a binocular microscope to assure an acceptable degree of disaggregation was effective in most samples. In a few fractions, later mineral counts revealed the presence of a significant proportion of aggregates; these were counted, and the screen analyses corrected.

The pebbles were identified in the laboratory by simple techniques. Mostly the pebbles were broken to examine fresh surfaces, limestone and dolomite were differentiated by acid reaction, and the other rocks and minerals were identified with a hand lens. Limonite, clearly secondary in many cases, was omitted from the analyses. Percentages are not reported for the fractions with less than 25 pebbles.

For the sand analyses, 1,000-gram samples of the minus 2mm fraction of the bulk samples were wet screened through Tyler standard sieves with openings approximately equivalent to the size-grade fractions of 1.0, .5, .25, .125, and .062mm.

The minus .062mm material from the original sample was used for determination of the silt and clay fractions by pipette analyses.

The sand fractions were digested in hydrochloric acid to remove carbonates and soluble iron compounds, and the heavy minerals were separated from the .250, .125, and .062mm fractions using bromoform. The heavy minerals were mounted on slides, and 200 grains were identified with a petrographic microscope.

The X-ray analyses were made by Glass; the heavy-mineral separations and counts and light-mineral counts were made largely by Constantine Manos.

The light minerals of the .5, .250, .125, and .062mm fractions were mounted on slides, the feldspars were etched with hydrofluoric acid, and the potash feldspars were stained with sodium cobaltinitrite. The minerals on these slides were counted with a binocular microscope.

Samples of the 2mm fraction dispersed in distilled water were used for separation of the minus 2-micron fraction for clay-mineral identification. The minerals in the minus 2-micron fraction were identified by X-ray diffraction using oriented-aggregate techniques. Determinations were made on a General Electric XRD-5 X-ray diffractometer, using Cu radiation.

FIELD RELATIONS

Described stratigraphic sections are presented at the end of this report for each of the twelve localities (fig. 1) from which mineral analyses are given. However, it seems appropriate to describe briefly the field relations of each locality and the genetic implications from these field observations. The sections are discussed in alphabetical order.

Bunker Hill Section

The exposures described occur in cuts made by minor stream dissection in the Illinoian till plain. The local topography reflects a shallow depression of few hundred feet across that has been drained by headward encroachment of a minor stream. The microtopography of the till-plain surface retained this small undrained or very poorly drained area during the deposition of the Sangamon accretion-gley, the Roxana Silt, and the initial phase of the deposition of the Peoria Loess. The deposits clearly reflect this history because they change upward from a typical Sangamon accretion-gley derived from lateral wash of the till surface to accretion-gley admixed with some eolian silt (Roxana), to Peoria Loess deposited in a wet—gleying environment, to typical Peoria Loess at the top. The date of complete drainage of the shallow depression thus would appear to be during early Woodfordian time and perhaps was initiated by the pluvial conditions associated with the advancing Shelbyville glacier.

Chapin Section

The Chapin Section is exposed in a deep highway cut near the crest of a valley wall, and the adjacent topography suggests that the area has been well drained continuously since the retreat of the Illinoian Jacksonville glacier. The Sangamon Soil has the characteristic appearance of a well-drained in-situ profile in till and is moderately deeply developed. Above the Sangamon Soil, a second profile occurs in the Roxana Ia, and this has the same relation and degree of mineral alteration as the superimposed soil that in Iowa has been called "late Sangamon" by Ruhe and others (1965). As it is developed on an eolian silt that appears to represent the arrival of the earliest Wisconsinan outwash in the headwaters of the Mississippi Valley, we consider it to be earliest Altonian. Still a third profile with a lesser degree of development occurs above this in the Roxana Ib, and the weathering of the top of the Roxana may be regarded as yet another soil. The modern soil occurs at the top of the section and is developed in Peoria Loess.

Donnellson Section

The Donnellson Section, exposed in the overburden of a quarry face, occurs at the position of the upland Kansan till plain. At the time it was described, several hundred feet of linear exposure was available for study. It showed that the soil surface declines in elevation laterally to an area a few feet lower, where a lens of typical accretion-gley immediately underlies the surficial loess in the lowest area of the soil surface.

In the in-situ section sampled, the B-zone of the Yarmouth Soil is in typical gradational sequence with the Kansan till below, but a sharp contact occurs between the Yarmouth B-zone and $2\frac{1}{2}$ feet of deposits overlying it that contain a GB-zone. The origin of this $2\frac{1}{2}$ feet of sediment presents a problem to which only a tentative answer is available. The topographic relations, the appearance of the deposits in the field, and the textural and mineralogical data obtained in the laboratory suggest that this thin unit is accretion-gley derived from the slightly higher elements of the topography during Yarmouthian time. During the time when a strongly atypical climate was created by the advance of the Illinoian glacier front to within a few miles of the locality, there was shallow dissection of the nearly flat till plain. Following the retreat of the Illinoian glacier, lateral sheet wash deposited the lens of Sangamon accretion-gley that probably also includes some Loveland Loess. After the dissection of the Kansan till plain and its veneer of Yarmouth accretion-gley, drainage conditions on the Yarmouth soil surface improved, because it also served as a source for the nearby Sangamon Soil accretion-gley. The improved surface drainage changed the environment from reducing conditions to oxidizing conditions and permitted the development of a Sangamon Soil GB-zone (a secondarily developed B-zone) in the Yarmouth accretion-gley. The secondary development of Sangamon Soil in the Yarmouth accretion-gley suggests the appropriateness of calling the profile a Yarmouth-Sangamon Soil. The presence of Wisconsinan loesses above the soil indicates that development proceeded only through Sangamonian time.

Effingham Section

The Effingham accretion-gley section occurs in an erosional scar on the side of a deeply excavated drainage ditch in the Illinoian till plain. This section is of particular interest because it was this locality that was cited as the representative example of gumbotil (Leighton and MacClintock, 1930; 1962; Brophy, 1959). It occurs under an area of exceptionally flat topography, although slightly higher areas occur to the northeast and southwest. As the drainage ditch affords linear exposures for several hundred feet, it can be observed that the accretion-gley thins quite gradually away from the locality sampled; this contrasts with the sharply terminated limits of many of the accretion-gley lenses that formed in depressions of more limited extent. The topographic relation indicates that the distance of lateral transport of the material in the accretion-gley here was greater than was the case in many of the localities observed. It differs also in that the zone of till which is leached of carbonate minerals below the accretion-gley is quite thin; just below the contact the till is limonite cemented, and it contains some dolomite.

A striking feature is the presence of krotovinas (probably crayfish burrows) distributed through more than 6 feet of the deposit. In each burrow, the fillings resemble the matrix material 1 to $1\frac{1}{2}$ feet higher in the deposit. The accretion-gley becomes progressively darker upward and is almost black at the top; consequently, the filling of each burrow is darker than the surrounding accretion-gley material. The distribution of the burrows shows that there was a progressively upbuilding surface in an environment that was alternately wet and dry.

Fairview Section

The Fairview Section occurs in roadcuts extending several hundred feet south from the bluff of a small valley. Away from dissected areas, the upland surface of the Illinoian till plain is relatively flat, but in the continuous roadcuts, the soil surface can be observed to decline very gently northward toward the valley bluff, and a thin, small lens of accretion-gley is present at the lowest point on the surface (Frye, Willman, and Glass, 1960). The in-situ section that was described and sampled is about 100 feet upslope from the small undrained depression but nevertheless is in a poorly drained situation.

Fort Madison Section

The Fort Madison Section was studied in roadcuts extending down a steep valley wall and in stream cuts at the bottom. This section is near outcrops described by Kay and Apfel (1929, p. 226, 227) as containing $8\frac{1}{2}$ to 11 feet of gumbotil. The earlier section is now covered but showed the same sequence as studied here. As it occurs within the area of Illinoian glaciation, the microtopography of the Yarmouth Soil surface can not be reconstructed, but the thickness of the accretion-gley implies the existence of a relatively extensive undrained depression. A well-developed in-situ Sangamon Soil in the top of the thin Illinoian till, which overlies the Yarmouth Soil accretion-gley, demonstrates that the locality has been well drained since the retreat of the Illinoian glacier. Furthermore, the presence of a GB-zone, secondarily developed in the top of the Yarmouth accretion-gley, indicates that drainage conditions at this locality had improved significantly before the Illinoian glacier advanced over the area.

An unusual feature of this locality is the presence of soil caliche nodules in the uppermost part of the calcareous till. The presence of a Cca-zone immediately below thick Yarmouth accretion-gley has been observed at several localities from northeastern Kansas to western Illinois.

In the basal part of the section, there is an accretion-gley that may be the Afton Soil, but the exposures are not adequate to permit definite conclusions.

Funkhouser Section

The Funkhouser Section was studied in minor erosional gulleys that were cut into the edge of a shallow highway borrow pit at the top of a prominent valley wall, at the west edge of Funkhouser Cemetary. The top of the Sangamon in-situ soil profile is slightly above the general level of the Illinoian till plain, and the soil developed in a relatively well-drained situation, even before the erosional dissection of that surface. Above the Sangamon Soil, a weakly developed podzolic soil profile occurs in the top of the Roxana Silt and below Peoria Loess. The Sangamon Soil is typical of well drained in-situ Sangamon profiles, and this conclusion is confirmed by the presence of a well developed zone of calcium carbonate accumulation (Cca-zone) just below the leached till. Internal drainage of the soil profile may have been improved by the presence of a bed of highly permeable outwash sand and gravel five feet below the base of the CL-zone of the profile.

Funkhouser East Section

The Funkhouser East Section was studied in roadcuts and adjacent minor erosional gulleys about 3/4 of a mile east of the Funkhouser Section. The top of the accretion-gley is at an elevation slightly below the general upland level of the Illinoian till plain, in contrast with the Funkhouser Section, which is slightly above the general level. The Illinoian till is continuous with that of the Funkhouser Section but the thick zone of outwash sand and gravel is not exposed. In contrast with the Effingham Section, which is about 3 miles distant, the micro-topography indicates that here the accretion-gley deposit formed in a small undrained depression on the till plain surface. The fact that this depression intermittently contained water from shortly after the withdrawal of the glacier is indicated by the presence of krotovinas that extend more than one foot downward into the leached till (CL-zone) below the accretion deposit. The absence of a recognizable soil at the top of the Roxana, in contrast with the Funkhouser Section but similar to the Effingham Section, suggests that dissection and the development of the present well-drained topography did not occur until after the deposition of the Roxana Silt.

Hipple Section

The Hipple Section occurs near the southern end of an extensive roadcut that extends more than 100 yards to the north. The relation of the several units in these cuts previously have been described and diagrammed (Frye, Willman, and Glass, 1960; Frye and Willman, 1963; 1965). At the northern end, the topography is at the upland level, and a typical in-situ Sangamon profile is exposed. Traced southward in the cuts, the soil surface declines on a gentle slope where the Sangamon Soil surface has been truncated slightly by erosion with the resultant development of a thin zone of pebbles as a lag concentrate. This surface continues downward on a gentle slope beneath the lens of accretion-gley, but the B-zone that occurs under the surface beyond the limits of the accretion-gley lens changes in character to a BG-zone and becomes much thinner as it passes below progressively thicker accretion-gley. At the top of the accretion-gley, a thin GB-zone has developed secondarily before deposition of the Roxana Silt (P-789).

The section described here is the accretion-gley section from which bulk samples were collected. It should be noted that bulk sample P-1319 includes in its sample interval the thin zone of lag concentrate and possibly also the uppermost part of the BG-zone on which it rests.

Lone Oak Section

The Lone Oak Section is included in this report, even though the Sangamon Soil is developed in Pennsylvanian shale, in order to compare clay-mineral alteration in a relatively homogeneous clayey material with clay-mineral alteration in glacial till. It occurs under a surface of gently sloping, dissected, and well-drained topography that is underlain by Pennsylvanian shale. However, the permeability of the parent material is quite low, and therefore the profile's internal drainage is poor.

As a thin lag concentrate of pebbles and cobbles derived from the Kansan till veneers the surface of the soil and conforms to the topographic slope of the soil surface, erosional dissection of the surface and development of the topography under which the soil is developed occurred after Kansan glaciation. Development of the Sangamon Soil did not continue through Wisconsinan time because the Wisconsinan loess above it contains the modern surface soil in its upper part. The locality occurs beyond the limit of Illinoian glaciation, but the episode of erosional dissection that shaped the topography of the shale surface may have occurred during the episode of unusual climate when the Illinoian glacier front stood near by.

Meridian Road Section

The Meridian Road Section is included in this report to show the degree of mineral alteration in an in-situ weathering profile that developed in Altonian age till. It occurs in an area of moderately undulating topography that retains some elements of glacial constructional land forms but has been modified by post depositional erosion. The topographic setting and the relatively high permeability of the material combine to give the profile exceptionally good drainage. Furthermore, at this locality, the cover of Peoria Loess is thin so that some effects of late Woodfordian and more recent weathering most likely extended through the surficial loess and continued to modify the Winnebago till below.

Panama-A Section

The Panama-A Section occurs in roadcuts adjacent to a valley wall and under a relatively flat and undissected intermediate surface of the Illinoian till plain. In the immediate vicinity, but at a somewhat higher elevation, well-drained and poorly drained in-situ Sangamon Soils are developed in the same till. As the lower unit of the accretion-gley deposit (bed 2) rests directly on calcareous till (bed 1), filling of the depression started very soon after the withdrawal of the glacier. The till is early Illinoian (Liman Substage), and this lower unit of the accretion-gley must be an Illinoian deposit. The thin unit (bed 3) of limonitic sand and silt, above the basal unit of accretion-gley, is oxidized and dolomitic, and the unit contains a clay-mineral composition similar to that of the till. These factors prompt the conclusion that it was deposited during a time of accelerated erosion when the front of the late Illinoian Buffalo Hart glacier stood less than 50 miles to the north-northeast. The overlying accretion-gley (beds 4 and 5) is typical of such deposits in the Sangamon Soil. It includes prominent krotovinas and indistinct bedding of more sandy materials. The next unit upward (bed 6) is predominantly sand and silt with a prominent humus zone at the top. It is overlain by another thin zone (bed 7) of silt, sand, and humus. The character of the deposits indicates that this small depression remained undrained from the withdrawal of the earliest Illinoian glacier until after the deposition of the upper humic zone (bed 7). As the section is capped only with Peoria Loess (bed 8), the conclusion is drawn that drainage of the area was effected during the episode of erosion that accompanied the advance of the Shelbyville glacier to a little more than 50 miles northeast.

CHANGES EFFECTED BY WEATHERING

Weathering causes major changes in the physical and mineralogical composition of the tills. In Illinois, limestone and dolomite form a major part of the tills, commonly ranging from 20 to 40 percent, and the solution of the carbonates alone makes a significant change in the appearance and properties of the tills. Further modification of the till produces the soil zonation previously described.

The changes in physical composition are reflected largely in changes in grain size, and the mechanical analyses serve as a means of evaluating these alterations. In the previous studies, the closely spaced samples provided more diagnostic data on changes in the physical character of the sand, silt, and clay fractions, particularly at the boundaries of the zones, than the more widely spaced bulk samples of the present study provide. However, the bulk samples permit evaluation of the pebble fraction. Although the coarse pebbles (larger than 32mm), cobbles, and boulders were excluded as not representative, few were encountered in the sampling. They were less than 1 percent in the exposed faces where the tills were sampled.

The changes in mineralogical composition are based on (1) rock identifications or pebble counts of the pebble fractions, 3 or 4 of which have enough pebbles to report percentages; (2) counts of the light-weight minerals in the very fine, fine, medium, and coarse sand fractions; (3) heavy-mineral analyses of the very fine, fine, and medium sand fractions; and (4) X-ray diffraction analyses of the minus 2-micron fraction.

Two or three bulk samples of calcareous till were collected at two localities and are useful for evaluating the degree of uniformity in the till. However, for purposes of evaluating changes effected by weathering in fractions coarser than 2 microns, the uppermost calcareous sample, which generally is near the top of the CC-zone, is considered to be more representative of the original composition of the weathered zone; it is used in calculations of mineral depletion.

As previously explained (Frye, Willman, and Glass, 1960, p. 7), the percent depletion of a mineral is estimated by comparing the change in percentage of the mineral from the unweathered to the weathered zone with the change in percentage of a reference mineral in the same zones. This assumes that the reference mineral suffered no loss in weathering. The method is used to compare relative changes between partially depleted minerals and between zones or parts of zones.

To facilitate reference to the described sections and to the tables at the end of the report, the bulk samples are identified in the following tabulation.

Identification of bulk samples by age, described section, and soil zone.

In-situ Profiles

	On Illinoian till			On Kansan till
Zone	Funkhouser	Fairview	Zone	Donnellson
B	P-1287		GB	P-1301
B	P-1324	P-1316	B	P-1300
CL	P-1323	P-1315	CL	P-1299
CC	P-1286	P-1314	CC	P-1298
CC	P-1322			

Accretion-gley Profiles

	Effingham	Hipple		Fort Madison
G	P-1279			
G	P-1278	P-1320	G	P-1291
G	P-1277	P-1319	G	P-1290
CL		P-1318	CL	P-1289
CC	P-1276		CC	P-1288
U	P-1275	P-1317		
U	P-1274			

Grain Size

Evaluation of the effect of weathering on grain size largely depends on the assumption that the deposit was uniform—that the weathered material above the calcareous till originally had the same mineral composition and grain size as the underlying calcareous till. In some of the exposures sampled, the changes in grain size through the weathered zone are so close to the changes anticipated that uniformity in the deposit seems probable. In others, it is clear that before weathering there was a vertical variation in grain size. Analytical errors are variable and difficult to evaluate, but their general effect is to make the tills seem less uniform than they actually are.

In general, the unweathered tills are largely mixtures of fragments of rocks and minerals that originally were well sorted—the clay from surficial clays and shales; the sand from sands and sandstones; the pebbles, cobbles, and boulders from gravels. Most of the medium sand and coarser fragments are water worn. Less than 20 percent of the sand and coarser fragments is angular material derived directly by glacial erosion of the bedrock. The percentage is higher in the clay and silt because of the easy erosion and disaggregation of shales to clay, silt, and fine sand, but there is slight basis for evaluating their state of disaggregation when picked up by the glacier.

The grain-size characteristics of the sands and silts mixed in the tills is shown in table 1 and figure 2. In most of the samples, there is 2 to 4 times more material in the medium sand than in the coarse sand, and the first peak of abundance generally falls in the medium or fine sand. A second peak generally falls in the coarse silt and a third in the clay fraction. This seems to be a general characteristic of sandy, silty, and clayey tills.

In a large proportion of natural silt deposits, as represented by both loess and water-deposited silts, the peak of abundance falls in the coarse silt. All samples in this study had this secondary peak in the silt size. Although comparison with other analyses indicates this is a real characteristic, it occurs at the change from pipette to sieve analyses, and the change of technique could exaggerate the effect.

The sand fractions of the tills have a grain-size distribution similar to that of the Quaternary sands of the region. The dominance of the medium and fine fractions is well shown by comparison with analyses of dune, outwash, and modern river sands of Illinois reported previously (Willman, 1942). In the dune sand, the peak is in the fine size or the fine-half of the medium size in all but one of 51 samples. More than 50 percent of the grains are in one grade size (2 sieve sizes) in 45 of the samples. In the outwash sands, the peak is in the medium size in 14 of 24 samples; the peaks in the other 10 samples range from very coarse to very fine sand. Half of the samples had 50 percent or more in one grade size. In the modern river sands, the peak was in the medium and fine grades in 19 of 22 samples. Two-thirds of the sand samples have 50 percent or more in one grade size. The persistence of the peaks in the medium and fine sizes and the high degree of sorting is related directly to the dominance of quartz and feldspar grains of these sizes in granitic rocks.

In these Quaternary sands, the fractions representing 75 percent of the total samples consist of over 70 percent quartz and 20 percent feldspar, and the average is about 95 percent quartz and feldspar. Because of increase in carbonates and other rock fragments, the percentage of quartz and feldspar declines in the coarser sand fractions and is 50 percent or less in the very coarse sand fraction.

The sand fractions of the unweathered tills have essentially the same grain-size distribution and composition as the Quaternary sands.

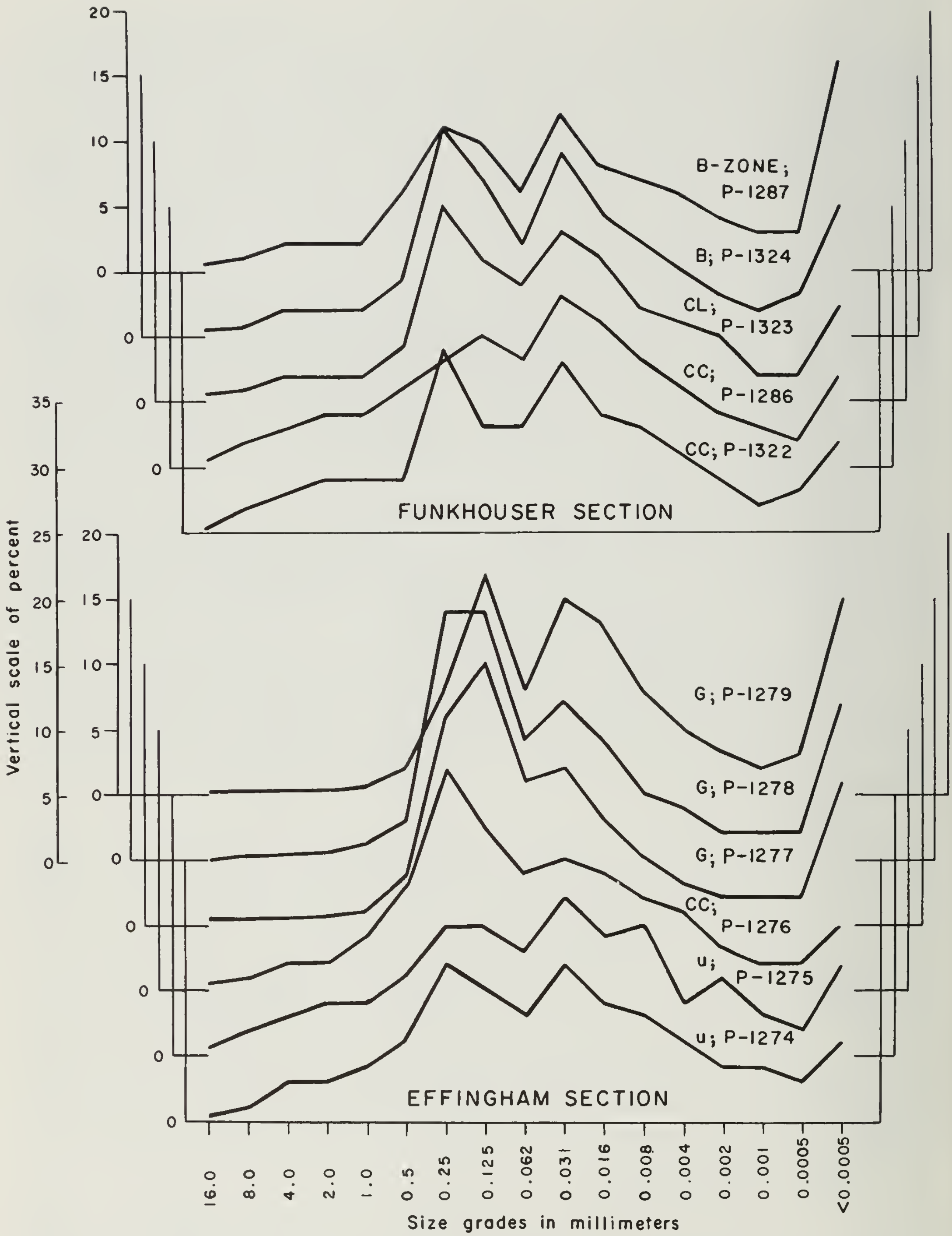

Figure 2. Grain-size analyses of bulk samples from Effingham and Funkhouser Sections.

From the mineral composition of the calcareous tills, the effect of weathering on grain size can be predicted, assuming uniform original composition, for in-situ soils, "gumbotils", and accretion-gleys.

In the in-situ profiles, an increase in the percentage of sand above the base of the leached zone would be anticipated because the sand size contains less carbonates than other fractions. A slight increase in clay content would be anticipated because leaching of the carbonates leaves some clay residue, the clay fraction contains less carbonate than the silt, and leaching of carbonates may disaggregate some calcareous shale grains. Pebbles and coarser fractions, relatively high in carbonates in the calcareous till, should show a noticeable decrease upward from the base of the leached zone.

At the base of the B-zone, an increase in clay, particularly in the minus .5-micron size, might be expected because of illuviation plus some clay addition from silicate decomposition, and the amount of clay might be expected to increase upward through the B-zone. In the upper part of the B-zone, with the most intensive weathering and greatest clay illuviation, a decrease in amount of coarse fractions would be anticipated, followed in the A-zone by a decrease in clay, an increase in silt and sand, and a decrease in pebbles.

If either the in-situ profiles or the accretion-gleys are "gumbotil", a different variation in grain size would be anticipated. The gumbotil hypothesis interprets the base of the B-zone as the advancing front of a zone of essentially complete chemical decomposition of silicates with clay enrichment almost entirely by silicate decomposition rather than illuviation. Weathering to this extent would result in loss of carbonates, feldspars, ferromagnesian minerals, all heavy minerals except the limited suite of the most stable minerals, and a large part of the less stable clay minerals. The most stable clay minerals and the clay minerals derived from weathering of silicates would be left. The resulting material would be a concentrate of the quartz in the sand and silt fraction, chert and quartzite in the coarse sand, pebbles, and cobbles all embedded in a clay matrix with a relatively high increase in percentage of material coarser than clay. A large removal of silica might increase the proportion of clay, but the surface characteristics of the silica grains do not suggest significant silica removal. None of the deposits sampled in this study have grain-size characteristics consistent with this interpretation.

In the accretion-gleys, a considerable range in grain size would be anticipated because they are sediments. In some places, a pebble concentrate at the base of the accretion-gley shows sheet wash of the till before accumulation of the accretion-gley. Because of slow accumulation in poorly drained areas, a sharp increase in clay content would be expected at the base of the accretion-gley. Sand normally would decrease upward in the deposit as surrounding areas become lower and are more deeply weathered. Pebbles and cobbles should be rare, but under wet conditions they could move on very low gradients into the accretion-gleys.

The bulk samples of calcareous tills in the six sections sampled are classed as sandy tills, ranging from 26 to 40 percent sand in the Illinoian tills and from 40 to 46 percent in the Kansan tills. With the exception of the Illinoian till at Hipple and Fairview, which are higher in silt, sand is the most abundant size in the calcareous tills sampled (table 1).

Pebbles in In-Situ Profiles

Funkhouser Section.—The decrease in the percentage of pebbles (about 40 percent) from the CC-zone to the CL-zone results from solution of carbonates. The presence of an equal quantity of pebbles in the CL-zone and B-zone indicates no great loss of noncarbonate pebbles in the B-zone.

Donnellson Section.—This section is similar to the Funkhouser Section, except that the upper sample, in the GB-zone, shows a decrease of two-thirds of pebbles from the B-zone sample; this is consistent with its interpretation as an accretion-gley secondarily weathered in the Sangamon profile.

Fairview Section.—The loss of 80 percent of the pebbles in the B-zone, whereas the pebble fraction contains only about 60 percent limestone and dolomite, supports other evidence that the upper part of the till originally did not contain as many pebbles as the lower part. The sharp decline of pebbles is between the CC- and CL-zones, where the difference should be caused only by leaching of carbonates. Here, also, there is no change in percentage of pebbles between the CL- and B-zones.

Pebbles in Accretion-Gleys

Effingham Section.—The uppermost calcareous till sample is partially leached, which accounts for most of the decrease in pebbles of about a third. The further loss to one-third of the original pebbles at the base of the G-zone, and the upward decline to less than 10 percent as many pebbles as in the calcareous till is consistent with accretion-gleys and not in-situ profiles. In an in-situ profile, this would require loss of 90 percent of the pebbles, only 50 percent of which are carbonates, although the relative amounts of the noncarbonate constituents, including pebbles of feldspars, granite, and basalt, remain approximately the same. Pebbles larger than 32mm in diameter were present in the calcareous samples, but no pebbles as large as 16mm were found in the upper two samples of the accretion-gley, which also is consistent with origin by accretion.

Fort Madison Section.—The percentage of pebbles decreases 85 percent at the base of the accretion-gley and 95 percent at the top. In the lower of the two samples, 9 percent of the pebbles in the 4mm fraction and 4 percent in the 2mm fraction are limestone, which again demonstrates that the material is a sediment and not a product of weathering.

Hipple Section.—The pebble concentration in the basal sample from the accretion-gley, higher than in the calcareous till, is consistent with the fact that some of the lag concentrate at the base of the accretion-gley was included in the sample. The presence of abundant pebbles in the base of the deposit supports its origin as an accumulation in a depression, or at least opposes an in-situ origin. The uppermost sample in the gley shows a decrease of about 75 percent in the number of pebbles over the number in the calcareous till, a much larger decrease than in the two in-situ profiles on Illinoian till.

Sand in In-Situ Profiles

Funkhouser Section.—The total sand shows an increase in the CL-zone, no change at the base of the B-zone, but a decline at the top of the B-zone to about the same as the decline in the calcareous till, which is close to the predicted change. The inference is that in this section the loss of carbonates by solution, in particular the loss of pebbles, is compensated by increase in clay content from weathering, so that the percentage of sand remains about the same.

Donnellson Section.—This section shows the same change as at Funkhouser, except the major decline in percentage of sand in the GB-zone at the top parallels the decline noted for the pebbles. Even in the most intensively weathered zone, the characteristic relatively sharp increase in percentage of the medium sand is preserved.

Fairview Section.—The sand fraction, like the gravel, shows a major decline (about 40 percent) in abundance at the top of the profile, suggesting again that the deposit was originally finer grained at the top. The decline of 23 percent in sand in the CL-zone is explained largely by the increase of 85 percent in amount of clay, which normally increases only a small percentage in this interval.

Sand in Accretion-Gleys

Effingham Section.—After reporting that the sand distribution in the Effingham Section, as described by Brophy (1959), seemed to be consistent with in-situ origin (Frye, Willman, and Glass, 1960, p. 16), our subsequent field examination of the section showed that it had the characteristics of an accretion-gley. This is supported by the mineralogical studies. The increase in sand content reported by Brophy (1959, sample E-6) is comparable with the increase shown by our sample (P-1276) immediately below the accretion-gley, which is calcareous till, although largely leached. The total sand content of the three accretion-gley samples is considerably higher than in Brophy's (1959) samples, which were probably taken at another part of the exposure. In our samples, there is no significant change in the percentage of clay, nor enough loss in pebbles, to account for the increase of 25 percent in sand content, and it seems more logical to relate the increase to variation during deposition of the accretion-gley. It is apparent, however, that the upward decrease in sand content in the accretion-gley can parallel closely the upward decrease related to dilution by clay in the in-situ profiles.

Fort Madison Section.—In the accretion-gley, the sand content decreases 30 percent at the base and 70 percent at the top. As about 75 percent of the carbonates had been leached from the calcareous sample immediately below the accretion-gley, the decrease in sand content is related largely to a 65 percent increase in clay content. It, therefore, is probably a depositional variation consistent with interpretation of the material as an accretion deposit. In comparison, the in-situ profile on the Kansan till at Donnellson shows a decrease of only 13 percent with only a slight increase in clay content in the B-zone. The sharp decrease in sand content at the top of the accretion-gley is also depositional, but it is entirely comparable with the decrease at the top of the in-situ profile at Donnellson, which is a secondarily weathered accretion-gley. Both are related to a sharp increase in clay content. This probably indicates a decrease in the rate of accretion-gley accumulation.

Hipple Section.—At Hipple the percentage of sand increases in the base of the accretion-gley and decreases in the top. The increase at the base is related to the lag concentrate on the underlying till. The decrease at the top is related to an increase in clay, and probably is more typical of the deposit as a whole than is the lower sample. The decrease in sand content cannot be related to mineralogical change, and therefore appears to be sedimentary.

The three accretion-gley profiles show more variability in sand content than the three in-situ profiles. Where two or more samples of the B-zone and accretion-gleys are available, they are similar in showing a decrease in sand content at the top. The characteristic peaks of abundance of the medium and fine sand, and the sharp increase in abundance of medium sand over coarse, inherited from original sand deposits, persists in the most deeply weathered samples and reflects derivation from the mature sands of Paleozoic sediments.

Silt in In-Situ Profiles

The percentage of silt is remarkably uniform in all 26 samples—calcareous and noncalcareous materials, in-situ profiles, and accretion-gley profiles. The striking variations in appearance and properties of these materials must be related to variations in other grade sizes. The lowest amount of silt is 30 percent in the CL-zone in the Donnellson Section; the highest is 44 percent in the CL-zone at Fairview and at the top of the accretion-gley at Hipple. The average is 36 percent and half the samples are within 3 percent of that amount, which would be an optimistic evaluation of the analytical error.

Funkhouser and Donnellson Sections.—In these two sections, the percentage of silt remains so uniform (2 to 3 percent variation), it would appear that no change takes place. However, there should be some loss because the silt fraction is more calcareous than the sand and clay fractions. Further, the grains of some readily weatherable minerals in this fraction should be decomposed more easily than in coarser fractions. To maintain such a uniform percentage, there must be compensating additions. The most likely source is silt from disaggregation of shale and siltstone.

Fairview Section.—In this profile, the increase of silt from 36 to 41 percent probably is related to the original variation that prevents effective interpretation of grain-size changes. In view of the increase in clay from 15 to 36 percent in the same samples, the increase in silt does not seem to be related to weathering.

Silt in Accretion Gleys

Effingham Section.—The slightly lower content of silt in the basal part of the accretion-gley than in the calcareous till well might be related to a somewhat higher than normal carbonate content in the silt fraction, which could be reflected in material washed from weathered slopes into the accretion-gley. This would be essentially the same result if weathered in-situ. The top sample shows a more significant increase in silt, but this seems to be related to an equally notable decrease in sand that is not consistent with the similarity of the samples in mineralogical composition. If the cause is weathering, the opposite change would be anticipated—a relative increase in proportion of sand. The slight increase in clay content could not account for variation in abundance of either sand or silt.

Fort Madison Section.—This accretion-gley likewise shows an increase in silt at the top, accompanied by a large increase in percentage of clay. Although 50 percent of the calcareous till below the accretion-gley is sand and pebbles, the upper part is 86 percent silt and clay.

Hipple Section.—In the accretion-gley, the silt content is uniform except in the basal sample where dilution by pebbles lowers the proportions of all other constituents.

In the in-situ profiles, the percentage of silt decreases at the top; in the accretion-gleys, the highest percentage of silt, accompanied by the highest percentage of clay, is at the top. However, the low range of variation in silt content reduces the apparent usefulness of the abundance of silt as a criteria for evaluating weathering, or profile types. The characteristic peak of abundance in the coarse silt is apparent in all samples, regardless of degree of weathering, which shows the difficulty in greatly modifying original grain size by weathering.

Clay in In-Situ Profiles

Funkhouser and Donnellson Sections.—In both of these sections, the percentage of clay in the CL-zone is essentially the same as in the calcareous material below, and it increases only slightly in the lower part of the B-zone. In the uppermost sample from the B-zone in the Funkhouser Section, the clay increases about 45 percent, and in the GB-zone at Donnellson, it increases 115 percent. In the Funkhouser Section, the increase is largely in the very fine clay (less than 0.5-micron fraction), but in the Donnellson Section, all fractions double in percentage.

Fairview Section.—The percentages are confused again by the effect of excess gravel in the calcareous zone, but the increase in clay of about 30 percent from the CL-zone sample to the B-zone sample is about the same as the average for the two B-zone samples from the Funkhouser Section.

Clay in Accretion-Gleys

Effingham Section.—Although the change in physical appearance at the base of the accretion-gley would suggest an appreciable increase in clay content in the accretion-gley, the analyses suggest only a slight increase. However, the amount of clay increases upward and represents a 45 percent increase at the top. The increase appears to be entirely in the percentage of the very fine clay, the other fractions remaining constant or slightly decreasing.

Fort Madison Section.—In the accretion-gley, the relation is similar; the increase is greater (60 percent at the base, 150 percent at the top) but entirely in the percentage of very fine clay.

Hipple Section.—The amount of clay increases in the accretion-gley, but again the increase in not large. The top of the accretion-gley contains about 35 percent more clay than in the calcareous till below. The increase is largely in the very fine clay.

In the accretion-gleys and in the in-situ profiles, there appears to be a large increase in clay content at the top of the profile. The exceptionally high increase in clay in the accretion-gley on the Kansan till may result from weathering after deposition of the accretion-gley, but a similar effect could be produced by a decline in the rate of accumulation resulting from the reduced gradient of the surrounding slopes.

Clay Minerals

The clay-mineral content of unweathered till of the several stratigraphic units in Illinois has been summarized (Willman, Glass, and Frye, 1963), and additional data, particularly for tills in the western part of the state, were presented more recently (Frye, Willman, and Glass, 1964; Glass, 1966). Earlier data on clay minerals of the buried-soil profiles on glacial tills in Illinois have been described (Frye, Willman, and Glass, 1960). Previously published data generally are not repeated in the tables in this report but are utilized in the discussion and conclusions.

Tills deposited by glaciers entering Illinois from the northeast have illite as the dominant clay mineral with minor amounts of chlorite. Kaolinite and montmorillonite also may be present in minor amounts. Tills deposited by glaciers entering Illinois from the northwest have montmorillonite as the dominant clay mineral with minor amounts of kaolinite and illite; chlorite is usually absent. Vermiculite derived from chlorite is known to occur in relatively unaltered tills only in those tills deposited by glaciers from the north-northeast.

Illite is defined here as all clay minerals of 10 Å basal spacing that do not expand when treated with ethylene glycol. Chlorite includes all nonexpandable 14 Å material, and any 14 Å nonexpandable vermiculite is included with chlorite. Kaolinite is identified by its characteristic diffraction peaks based on a 7.2 Å periodicity. Montmorillonite includes all clay material that yields a well-defined diffraction peak at about 17 Å with ethylene glycol treatment. Therefore, all "swelling" chlorite and vermiculite is included as montmorillonite.

The alteration of chlorite and illite by weathering eventually produces expandable clay-mineral types. Chlorite alters to mixed vermiculite-chlorite and then to nonexpandable 14 Å vermiculite. With more intense weathering, the vermiculite expands to intermediate mixed-lattice types between 14 Å and 17 Å; with sufficient intensity of weathering, swelling to 17 Å occurs. This material is then indistinguishable from montmorillonite.

Alteration of illite proceeds through mixed-lattice stages that expand with ethylene glycol to values between 10 Å and 17 Å. When the alteration is sufficient that the expansion is to about 17 Å, the material is also called montmorillonite. Under certain conditions illite may alter to a nonexpandable 14 Å vermiculite. Weathering of vermiculite derived from illite will produce mixed-lattice material between 14 Å and 17 Å, and with sufficient alteration, this material also will expand to what is called montmorillonite.

The weathering of montmorillonite is expressed only by a broadening of X-ray diffraction peaks caused by decreased particle size or poorly crystallized material, but there is no change in peak position when treated with ethylene glycol. There is no evidence to indicate that kaolinite is altered during weathering.

A clay material of particular significance in the B-zones of in-situ profiles has been referred to by us informally as B-clay (Frye, Willman, and Glass, 1964). This material is recognizable by the shape of its X-ray diffraction curve. On diffraction curves, after treatment with ethylene glycol, a broad, diffuse diffraction peak ranges across the area from 10 Å to 17 Å and replaces the sharply defined peaks commonly produced by montmorillonite or vermiculite. This material is commonly referred to as either montmorillonite or mixed-lattice material. This heterogeneous swelling material (B-clay) earlier was informally called expandable vermiculite (Frye, Willman, and Glass, 1960) because it was thought to be an alteration product of vermiculite derived from illite and chlorite. As that term suggested that it was a mineral species, it was dropped. Furthermore, diffraction analyses of many more profiles of weathering suggest that such heterogeneous swelling material may be produced by weathering of montmorillonite as well as illite and chlorite. This diagnostic heterogeneous swelling material represents an end stage of Pleistocene weathering of clay minerals in an oxidized, well-drained in-situ profile. It is extremely sensitive to treatment by saturation with cations such as Mg, K, or Ca during sample preparation. The "memory" of this material for interlayer cations lost during alteration readily causes the re-formation of vermiculite when saturated with Mg and perhaps illite when saturated with K. Therefore, clay-mineral identifications by X-ray diffraction analyses that include cation saturation of samples prior to analysis will give results not comparable with those made without prior cation treatment.

The data in table 2 show the clay-mineral composition of all samples, the relative abundance of calcite and dolomite in the less than 2-micron fraction by listing the X-ray diffraction counts per second, and the presence or absence of goethite, lepidocrocite, and kaolinite. The degree of alteration of chlorite is indicated by the observed presence or absence of the first, third, and fourth order X-ray reflections. In table 2, all reflections are present in true chlorite, whereas only the first order would remain in vermiculite. Alteration of vermiculite to montmorillonite would cause elimination of the first order reflection. The first order reflection often is masked by the presence of large amounts of montmorillonite in mixtures.

In order to facilitate a graphic representation of clay-mineral changes in stratigraphic sequence, a numerical value called D. I. ratio was devised by dividing the X-ray diffraction intensity (counts per second) of the 10 Å spacing (8.8°2Θ) for illite by that for the 7.2 Å spacing (12.4°2Θ) for kaolinite and chlorite (Frye, Glass, and Willman, 1962). As kaolinite is generally unaltered during the weathering process, variations in the ratio indicate changes in the proportions of illite and chlorite.

Alteration of chlorite is shown by a decrease in intensity of the 7.2 Å spacing causing an increase in numerical value for the D. I. ratio. This value increases upward in the profile until that point is reached where alteration of illite begins, as shown by a decrease in intensity of the 10 Å reflection. The D. I. ratio then will begin to decrease in value and continue decreasing as long as alteration of illite occurs. This reversal in D. I. ratio provides a means of evaluating the relative amount of depletion of illite and chlorite and the intensity of weathering. For Woodfordian tills, for instance, the D. I. ratio will only increase because no illite is altered. On the other hand, tills of Illinoian age show both the increase and decrease in D. I. ratio. Where calculable, the D. I. ratios are listed in table 2.

Clay-Mineral Composition of Soil-Profile Zones

Unaltered till (U).—Unaltered till shows no clay-mineral alteration except along oxidized joints that extend into the parent material. Examples of unaltered till showing the wide variability of Illinoian till composition are given in table 5.

Table 5. – Clay–Mineral Composition of Unaltered Illinoian Tills

	Sample	Montmo- rillonite	Illite	Kaolinite & Chlorite	Substage
Hipple	P-1317	0	74	26	Buffalo Hart
Funkhouser	P-1321	12	62	26	Jacksonville (?)
Funkhouser	P-1284	17	59	24	Jacksonville (?)
Effingham	P-1274	19	59	22	Jacksonville (?)
Chapin	P-2099	42	38	20	Liman

CC-zone.—This zone is characterized by the presence of carbonate, usually both calcite and dolomite, and oxidation of the till generally forms limonite and goethite. Accompanying the oxidation of the till is the alteration of chlorite, the most readily altered of all clay minerals. Chlorite and oxidation are the most sensitive indicators of weathering, and even slight oxidation of the till results in a loss of chlorite to a depth well below the zone of leaching of calcite. No other clay-mineral change occurs in this zone. The decrease in chlorite can be observed for all tills deposited by glaciers that entered Illinois from an easterly direction (table 2). Till deposited by glaciers from the northwest generally does not contain chlorite and, therefore, does not show this feature. Accompanying the decrease in chlorite is an increase in the D. I. ratio.

CL-zone.—Leaching of carbonates is accompanied by further depletion of chlorite with continued increase in the D. I. ratio. However, the first detection of illite alteration may occur in the upper part of the CL-zone. This is shown by the Funkhouser East Section (table 2). Sample P-1284 shows unaltered till; P-1280 (CC-zone) indicates chlorite loss with increase in montmorillonite; and P-1281 (CL-zone) shows illite loss with further increase in montmorillonite. The D. I. ratio, in response to chlorite loss followed by illite loss, increases in the CC-zone and then decreases in the CL-zone. Identical relations may be observed for the Funkhouser Section. The alteration of illite in the CL-zone can be seen in the Chapin Section (P-2103) and may even be observed in Kansan till at the Donnellson Section (P-1306).

B-zone.—In Illinoian tills younger than Jacksonville in age, alteration of illite extends no lower than the B-zone. This may be shown in the till of Buffalo Hart age at the Fairview Section (P-677). In all sections where illite depletion extends into the CL-zone, depletion is greater in the B-zone and continues to the top of the profile. A decrease in the D. I. ratio accompanies this depletion.

Accompanying the reduction of both chlorite and illite is an increase in expandable material, generally referred to in the literature as montmorillonite.

However, with sufficient intensity of weathering in the B-zone, this material commonly becomes rather diffuse in its expression on an X-ray diffraction curve and then is referred to as heterogeneous swelling material (B-clay). The diffuse and broad nature of the X-ray diffraction curve results in a reduction in area and intensity of the diffraction peak of montmorillonite. Therefore, for this type of material, the calculation of the percent of montmorillonite may become impractical, and clay-mineral values are omitted in table 2 for samples P-2109, P-2110, P-2111 at the Chapin Section. For Kansan tills which initially contain large amounts of montmorillonite, the more intense weathering in the B-zone is expressed principally as a broadening of the diffraction peak for montmorillonite. This broadening of montmorillonite diffraction peaks and the development of heterogeneous swelling material by weathering is characteristic only of a well-drained oxidizing environment and not the poorly drained, reducing environment of the accretion-gley or G-zone. Kaolinite may be formed in the B-zone, but the evidence is not conclusive.

G-zone.—This zone, which consists of material deposited by incremental accretion in a generally wet, poorly drained, organic-rich, reducing environment, is characterized by the presence of well-crystallized montmorillonite and vermiculite and by absence of goethite. Thus, X-ray diffraction analyses of unweathered accretion-gley show sharp and well-defined peaks for montmorillonite and sharp reflections for vermiculite, generally with illite present in only small amounts, or absent. The source of the material entering the gleying environment is the weathering products of the till on the adjacent very gentle slopes, that is, material with a composition similar to that described for the A-zones and B-zones of the in-situ Sangamon Soil profiles. As this degraded or heterogeneous swelling clay material (B-clay) is moved from its oxidizing environment of origin into the reducing environment of deposition, pedogenic processes, operating particularly on the minus .5-micron particles, cause the formation of well-ordered montmorillonite (Jackson, 1965). Thus, in the case of the Sangamon accretion-gleys, montmorillonite is pedogenically formed from material that was degraded from illite and montmorillonite. This is demonstrated by the much higher content of montmorillonite and much lower content of illite in the accretion-gley than in either of the adjacent tills or in the in-situ soils that developed in them; therefore, at least some of the pedogenic montmorillonite must have been formed from degraded illite, as well as from degraded montmorillonite. Furthermore, as the content of illite in the Sangamon accretion-gley is even less than that in the B-zone of the Sangamon in-situ soil profiles, there is the implication that some of the very finely divided illite may be converted in the gleying environment directly to montmorillonite. It is reasonable to conclude that the vermiculite or chlorite of the accretion-gley are regenerated from the material degraded from chlorite and vermiculite.

The clay-mineral composition of the accretion-gley is distinctly different from that of the B-zone of the oxidizing in-situ environment, which has broad diffraction peaks for montmorillonite or heterogeneous swelling material (B-clay). Chlorite and vermiculite are commonly absent, but illite generally is still present in significant amounts. The G-zone always rests on a BG-, CL-, or CC-zone and never on a B-zone. Extremely sharp changes in clay-mineral composition occur at the contact between the till and the accretion-gley, as shown by the following pairs of samples: Effingham Section, P-1276B and P-1277; Funkhouser East Section, P-1281 and P-1282; Fort Madison Section, P-1289 and P-1290. On the other hand, the change in clay-mineral composition from the CL-zone to the B-zone of in-situ profiles is always gradual with no sharp contrasts, as shown by the following pairs of samples: Lone Oak Section, P-1841 and P-1842; Donnellson Section, P-1306 and P-1307; Chapin Section, P-2106 and P-2107; Funkhouser Section, P-1323 and P-1324.

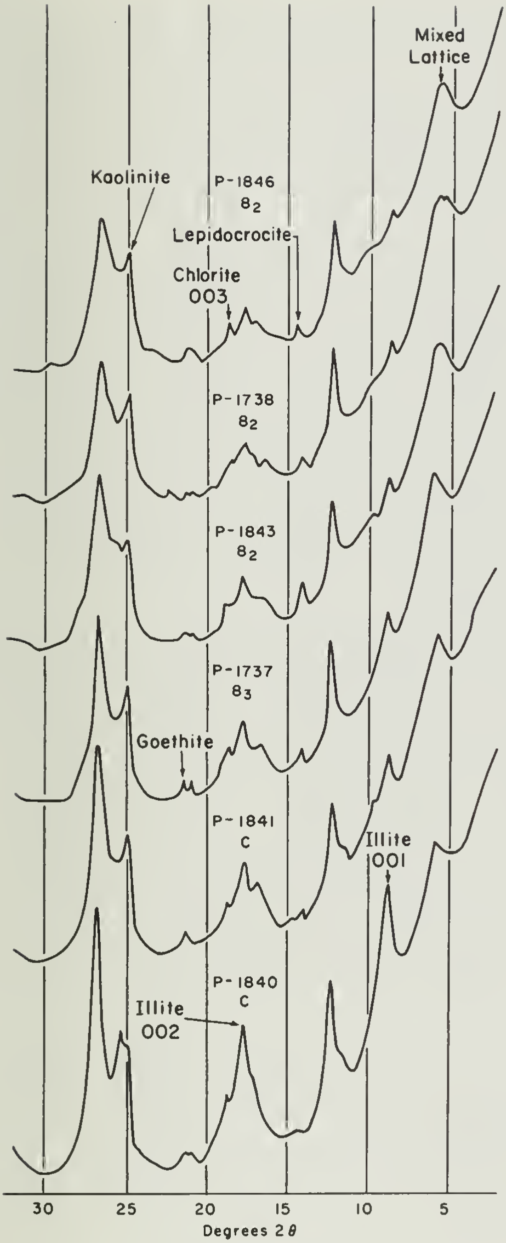

Figure 3. X-ray diffraction curves of samples from Lone Oak Section. In-situ Sangamon Soil developed in Pennsylvanian shale. Note progressive upward decrease in illite.

A-zone.–This zone is shown in only one section. At the Fairview Section, it has a similar mineral composition to the B-zone (P-681 and P-682).

BG-zone.–This zone, present in the Hipple Section (P-783 and P-784), is only 0.8 foot thick and shows characteristics of both the G- and B-zones. The sharp mineralogical change at the contact of the CL- and BG-zones (P-1318 and P-783) is characteristic of an accretion-gley, but the presence of goethite, the absence of pedogenic chlorite or vermiculite, and the presence of substantial illite identify this material as a gleyed B-zone.

GB-zone.–This zone is produced by secondary weathering of accretion-gley in an oxidizing environment. In this situation, the homogeneous swelling montmorillonite of the G-zone is converted to heterogeneous swelling material, and the oxidation causes the formation of goethite and the destruction of the pedogenic vermiculite that formed in the accretion-gley. At the Donnellson Section, a thin zone of accretion-gley has been converted entirely to a GB-zone, and it also occurs in the top of the accretion-gley at the Fort Madison and Hipple Sections.

Sangamon Soil

The buried Sangamon Soil profiles will be discussed in three groups. First, an in-situ Sangamon Soil developed on relatively homogeneous Pennsylvanian shale (Lone Oak Section); second, three in-situ Sangamon Soils (Chapin, Fairview, and Funkhouser Sections) developed on Illinoian till; and third, five Sangamon Soil accretion-gleys (Bunker Hill, Effingham, Funkhouser East, Hipple, and Panama-A Sections) resting on Illinoian till.

Sangamon Soil on Shale.–The Lone Oak Section presents an extremely uniform gradational sequence of clay-mineral compositions. This is shown graphically by the X-ray diffraction curves presented in figure 3 and by the data in table 2. The C-zone shale at the base of the profile (P-1840) is high in illite, but it shows some alteration of chlorite to mixed vermiculite-chlorite and vermiculite. Alteration of illite begins at the top of the C-zone (P-1841), the amount of illite gradually decreases, and the amount of vermiculite and mixed-lattice clay minerals gradually increases from the C-zone into the B_2-zone. This gradual decrease in illite can be seen in figure 3 by the decrease in intensity for the major peak of illite at 10 Å (8.8°2θ). As complete expansion to 17 Å (5.1°2θ) is not observed, no montmorillonite is identified. Intermediate swelling values between 14 Å (6.1°2θ) and 17 Å (5.1°2θ) approach, but do not reach, 17 Å upward in the profile. This indicates that the illite has altered to dioctohedral vermiculite. This decrease of illite is also reflected in D. I. ratios that show values for the B_3-zone (P-1842, P-1737) intermediate between the B_2- (P-1843) and C-zones (P-1841). The gradual decrease of illite upward through the B_3-zone stabilizes in the B_2-zone, as does the increase in expandable material. Although the decrease of illite and increase of vermiculitic expandable material is clearly caused by weathering alteration of the clay minerals, the calculated increase in kaolinite may be caused by the formation of kaolinite in the B-zone, but it may be, in part, an apparent in-increase and, actually, an artifact of the method of calculation. The section is unique in that the alteration of clay minerals does not produce the more highly expandable materials that occur in profiles developed on glacial till. In all other respects, this soil has characteristics similar to those developed on till. Both goethite and lepidocrocite occur in oxidized samples.

Sangamon Soil on Till.—Of the three in-situ Sangamon Soils developed in Illinoian till, two (Fairview and Funkhouser) present continuous upward changes in illite, chlorite, and montmorillonite. In the Fairview Section, a decrease in chlorite with a rise in D. I. ratio (P-674A, P-675, P-676) is observed from the CC-zone through the CL-zone. No loss of illite occurs until the base of the B-zone, where increase in montmorillonite is accompanied by a decrease in D. I. ratio (P-677). This trend continues upward to the top of the profile. Traces of vermiculite remain throughout the profile, as shown by the first-order reflections. It is important to note that in the in-situ profiles the decrease in illite and increase in montmorillonite is gradual and continuous. There are no sharp discontinuities in amounts of illite and montmorillonite. These continuous changes in clay minerals are typical of the oxidized, in-situ soil profile. In addition, the in-situ profiles contain poorly defined, heterogeneous swelling material (B-clay) in the B-zones, rather than well-crystallized montmorillonite.

Almost identical relations are observed in the Funkhouser Section. Depletion of chlorite occurs with increase in D. I. ratio (P-1321, P-1322, P-1286) through the CC-zone. The chlorite is completely eliminated in the B-zone (P-1324). Illite depletion with increase of montmorillonite and decrease in D. I. ratio (P-1323, P-1324, P-1287) begins in the CL-zone and continues to the top of the profile. Illite alteration was first observed in the B-zone at Fairview, but the till at Funkhouser is older, and alteration of illite has progressed to deeper levels. Goethite is present in all oxidized zones.

The typical clay-mineral changes caused by weathering in an in-situ soil profile on till are shown by the sequence of X-ray diffraction diagrams for the Funkhouser Section in figure 4. The unaltered till (P-1321) is high in illite with lesser amounts of chlorite, montmorillonite, and kaolinite. Note the decrease in intensity of the illite peak at 8.8°2θ upward through the profile. As was observed in the Lone Oak Section, this decrease is gradual and continuous, but a fair amount of illite remains (22 percent) in the B-zone. The alteration of illite causes the major part of the increase in montmorillonite at 5.0°2θ. In particular, note the broad, diffuse diffraction peak of the "montmorillonite" in the B-zone (P-1324). This feature is typical of the diffraction curve for the heterogeneous swelling material of the B-zones of in-situ profiles. The diffraction peak is distinctly not the well defined type of montmorillonite.

The weathering of chlorite can be followed by observing diffraction peaks for the (001) and (003) orders. The third order peak gradually decreases and is no longer apparent in the B-zone. The first order peak is sharply visible upward to the CC-zone, but it is masked by the expandable material in the CL-zone. Peaks for carbonate, goethite, and quartz are indicated.

In all the in-situ profiles examined where the intensity of weathering was sufficient to cause alteration of illite, a similar sequence of clay-mineral changes occurs.

The Chapin Section differs primarily in that the percentage of montmorillonite in the unaltered till is equal to, or greater than, illite (P-2099, P-2100). Therefore, the increase in montmorillonite and decrease in illite will be less spectacular than in the Fairview and Funkhouser Sections. However, decrease in chlorite with increase in D. I. ratio occurs (P-2099, P-2100, and P-2102), followed by a decrease in illite and D. I. ratio and an increase in montmorillonite (P-2103, P-2108). Again goethite is present throughout the oxidized material. Thus, when this initial montmorillonite difference is taken into account, it appears that the typical sequence of mineral compositions upward through the B-zone is quite similar to the other two sections. The poor diffraction intensity for the heterogeneous swelling material in the B_2-zone (P-2109, P-2110, P-2111) makes calculation of the percentage of montmorillonite impractical.

Sangamon Accretion-gley.—When we turn to the Sangamon accretion-gleys, it is apparent that they all differ in their succession of clay-mineral assemblages from the Sangamon in-situ profiles on till. The contrast is shown by the X-ray diffraction curves for accretion-gley in the Funkhouser East Section (fig. 5) when compared with those for an in-situ profile in the Funkhouser Section (fig. 4) and with the values for clay-mineral composition shown in table 2. The in-situ profile shows a gradational sequence of clay-mineral changes upward into the B-zone, and all samples contain goethite. The accretion-gley section shows a similar sequence of clay-mineral changes from the unaltered till only up through the CL-zone. The loss of chlorite can be followed through the CC-zone (P-1280) into the CL-zone (P-1281) by observing the intensity of the diffraction peaks for the first and third orders. Some chlorite or vermiculite is still present in the CL-zone (P-1281). The loss of illite, which begins in the CL-zone, can be followed upward by observing the decrease in intensity for its major peak for these three samples. Goethite is present in the CC- and CL-zones. However, at the base of the accretion-gley or G-zone, there is a sharp discontinuity in clay-mineral composition. At this point, the illite content abruptly drops, and a most striking increase in well-crystallized montmorillonite occurs. Note the difference between the diffraction curves in figure 5 across the contact from the CL-zone to the G-zone (P-1281 and P-1282), as compared to that in figure 4 from the CL-zone to the B-zone (P-1323 and P-1324). Also noteworthy is the sharpness of the montmorillonite diffraction peak for the accretion-gley as compared to the heterogeneous swelling material of the B-zone. Accompanying the increase in montmorillonite and decrease in illite is an abrupt increase in chlorite or vermiculite. This is best seen at the third order reflection for chlorite (P-1282), where its intensity has abruptly become greater than the adjacent peak for the second order reflection for illite. This does not occur in an in-situ weathering sequence, because chlorite and vermiculite are readily eliminated by destructive processes. This sharp increase in montmorillonite and vermiculite can be explained only by constructive processes resulting in the pedogenic formation of clay minerals in the specialized reducing environment of the accretion-gley. Furthermore, goethite is generally lacking from the G-zone, whereas it is commonly present throughout the in-situ profiles. As at several other localities, the lowest sample from the G-zone is

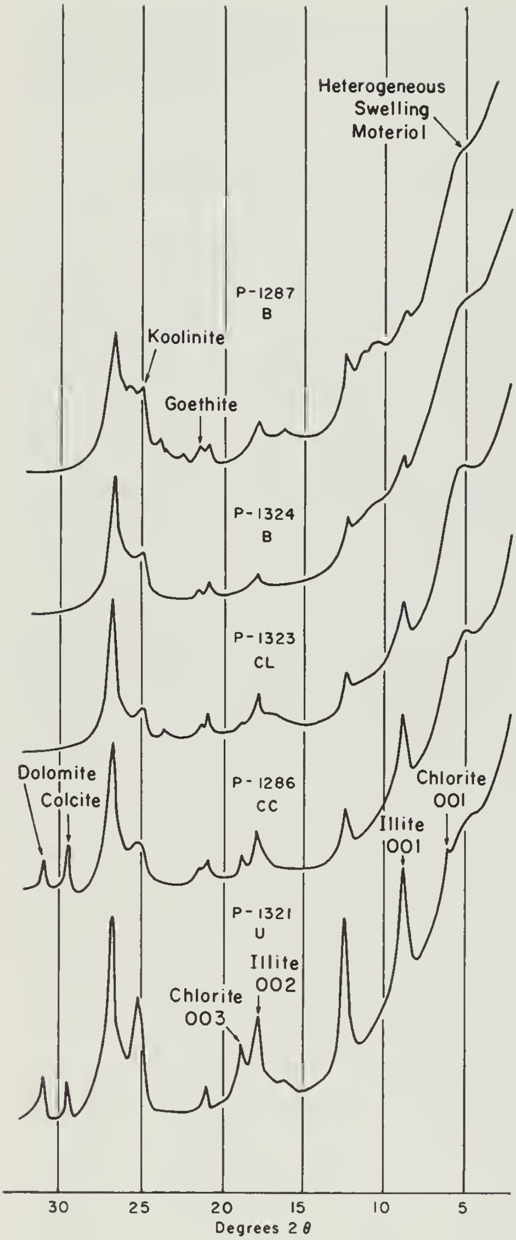

Figure 4. X-ray diffraction curves of samples from Funkhouser Section. In-situ Sangamon Soil developed in Illinoian till. Note progressive upward decrease in illite, and the occurrence of heterogeneous swelling material (B-clay) in the B-zone.

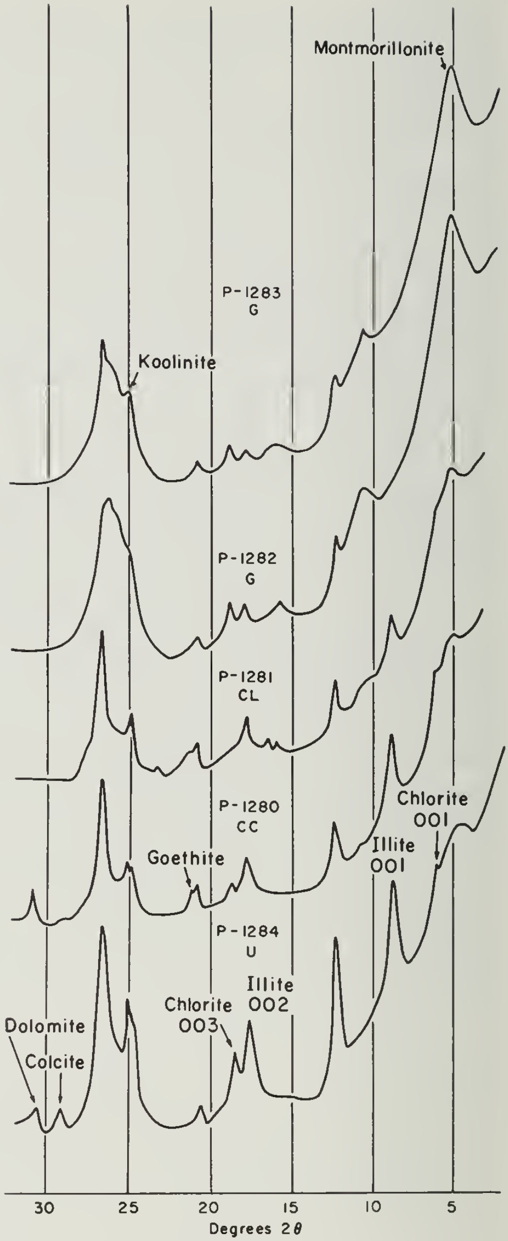

Figure 5. X-ray diffraction curves of samples from Funkhouser East Section. Sangamon Soil accretion-gley on Illinoian till. Note the sharp change in clay-mineral composition between the CL-zone and G-zone.

only an inch or two above the highest sample from the underlying till. The laboratory data thus confirm the field observation that this contact is not gradational. The Funkhouser and Funkhouser East Sections are adjacent to one another, thus precluding the possibility of climatic differences.

This spectacular mineralogical change also can be observed in the data for the Effingham Section (table 2), where the difference between samples P-1276B (CL-zone) and P-1277 (G-zone) is only a few inches, but the content of illite drops from 72 to 15 percent and montmorillonite increases from 15 to 70 percent. Strong development of vermiculite also occurs in the accretion-gley, and no goethite is present.

The Hipple Section shows the typical loss of chlorite from the CC-zone through the CL-zone without loss of illite (table 2). A thin BG-zone occurs between the CL- and G-zones. In the BG-zone goethite is present, and pedogenic chlorite or vermiculite, which are typical of a G-zone, have not developed. This zone is characterized by a substantial amount of montmorillonite, but it has an illite content in the range of the in-situ B-zones. These characteristics confirm the field relations that the zone has developed as a secondarily gleyed B-zone (P-783 and P-784).

The G-zone shows again the typical low illite and high montmorillonite compositions, the absence of goethite, and also the presence of pedogenic chlorite (P-785 and P-786). Post-depositional weathering of the accretion-gley before deposition of Roxana Loess has resulted in the formation of a GB-zone (P-789) in the top of the accretion-gley. This is indicated by a noticeable broadening of the montmorillonite diffraction peak and the elimination of pedogenic chlorite or vermiculite, as well as by the field relations. The broadening of the diffraction peak makes calculation of the percentage of montmorillonite impractical.

The Bunker Hill Section contains at the base typical accretion-gley (P-1418) with characteristic well-crystallized montmorillonite, low illite, pedogenic chlorite or vermiculite, and goethite is absent. The overlying sample of Roxana Silt (P-1419), although high in montmorillonite and low in illite, contains no vermiculite, and this composition is consistent with the admixing of Roxana Silt with lateral sheet wash into the gleying environment. Sample P-1420 of the overlying Peoria Loess contains much more illite than occurs in accretion-gley and has a composition typical of Peoria Loess (Frye, Glass, and Willman, 1962). Deposition of Peoria Loess in a gleying environment is indicated by its gray color and field relations.

The accretion-gley in the Panama-A Section contains as much as 90 percent of well-crystallized montmorillonite in the minus 2-micron fraction. The high illite Illinoian till at the base (P-1394, CC-zone) is overlain with sharp discontinuity by accretion-gley (P-1395) that contains a bed of sand and silt with till composition (P-1396). The overlying accretion-gley displays the typical characteristics of other accretion-gleys. However, the gleyed Roxana Silt above (P-1401) has the same clay-mineral composition as the accretion-gley. In the Farmdale (P-1403), the clay-mineral composition is similar, except for the broadening of the montmorillonite diffraction peak and the loss of vermiculite which are indicative of weathering. The overlying Peoria Loess (P-1404) has a typical composition with higher amounts of illite, lower montmorillonite, and some detrital chlorite. It appears that the gleying environment persisted through Farmdalian time and that there was weathering of the gleyed silt prior to the deposition of the Peoria Loess.

Yarmouth Soil

The succession of clay minerals in the two Yarmouth Soil profiles is strikingly different from that in any of the Sangamon Soils. These profiles occur on Kansan till from the northwest, and montmorillonite is the dominant clay mineral in the till. Chlorite is generally not present in these tills. In the in-situ profile at the Donnellson Section, the small content of illite present in the till (15 percent) decreases at the top of the CL-zone (P-1306) and diminishes upward through the B-zone to 6 percent (P-1308). Goethite is present in all samples. The D. I. ratio also decreases upward. The overlying GB-zone (P-1309 and P-1311) shows no detectable illite and a progressive upward broadening of the montmorillonite peak. This would indicate that the GB-zone is more weathered than the underlying B-zone and that the weathering occurred before deposition of the overlying loess. This upper GB-zone represents a Sangamon Soil developed in Yarmouth accretion-gley, and the alteration of the montmorillonite has proceeded to a significantly greater degree than is true in the GB-zone at the top of the Yarmouth accretion-gley at the Fort Madison Section, where the GB-zone is overlain by Illinoian till.

X-ray diffraction curves for Kansan till and Yarmouth accretion-gley are shown for the Fort Madison Section in figure 6. The till (P-1294, P-1288, P-1289) is characterized by well-crystallized montmorillonite with prominent amounts of kaolinite and lesser amounts of illite. Percentages of over 60 percent montmorillonite are common for western-derived tills. The amount of kaolinite is always greater than for illite, whereas the reverse is true for tills of Illinoian age. No significant change is observed in clay-mineral composition for the CC-zone through the CL-zone. The overlying accretion-gley (P-1290) contrasts sharply with the material below by its large increase in montmorillonite, decrease in both illite and kaolinite, and absence of goethite. The secondary modification of accretion-gley by weathering in an oxidizing environment is illustrated by the sample from the GB-zone (P-1295). Here there is a noticeable broadening of the peak for montmorillonite, and goethite reappears.

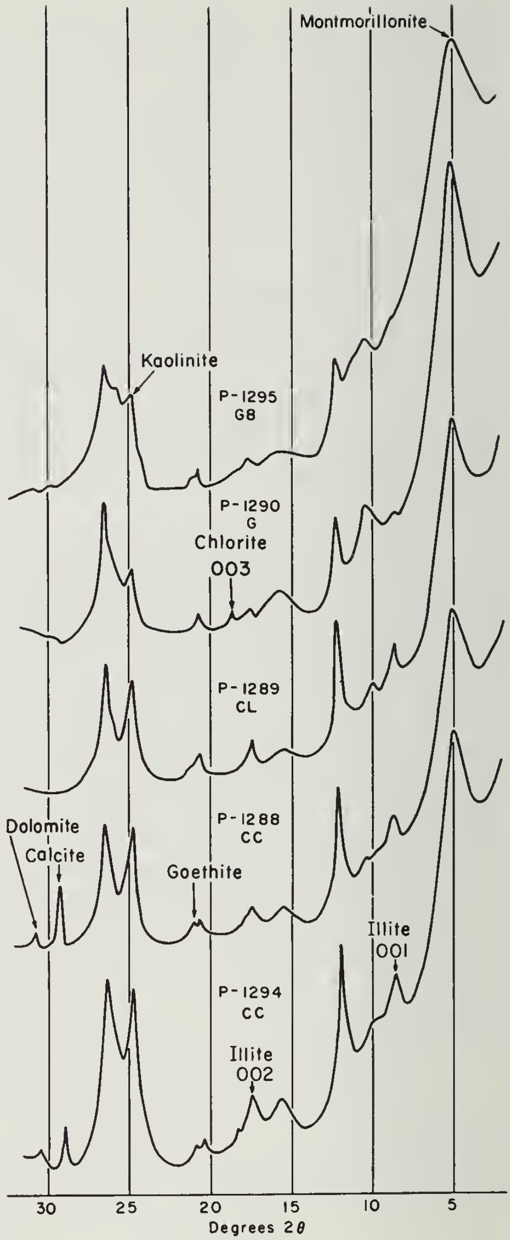

Figure 6. X-ray diffraction curves of samples from Fort Madison Section. Yarmouth Soil accretion-gley on Kansan till. Note the effects of weathering of montmorillonite in sample P-1295.

Soil on Winnebago Till

Clay-mineral data for one profile developed on Winnebago till (Meridan Road Section) are included in table 2. This till is initially high in illite, and the upward sequence of clay minerals is similar to that in the in-situ Sangamon Soils. However, depletion of illite appears to start in the B_2-zone, in contrast to the Sangamon Soils developed on tills of Jacksonville and Liman ages and the Yarmouth Soil profiles where depletion starts in the CL-zone. Furthermore, vermiculite persists upward throughout the profile whereas it is eliminated in the upper part of most Sangamon profiles. These data show that depth of illite alteration decreases with decreasing age of profile. Sangamon Soils on till of Buffalo Hart age have illite depletions to the base of the B-zone (Fairview Section); soils on till of Altonian age have illite depletion into the B_2-zone; and soils on till of Woodfordian age display no measurable depletion of illite in the B-zone.

Common Rocks and Minerals

Limestone and Dolomite

The distribution of limestone and dolomite in the weathered zone is controlled by both composition and grain size. The base of the leached zone (CL-zone), as determined by conventional field practice of visual or hearing check for effervesence with HCl, is a relatively sharp line that commonly can be located within an inch. Generally, it coincides with a sharp change in color, texture, and weathering character on an exposed surface. Throughout this discussion, the term calcareous is used in its field meaning to designate the presence of calcite, dolomite, or both.

The considerable difference in the solubility of limestone and dolomite, as previously noted (Frye, Willman, and Glass, 1960), results in almost complete leaching of limestone to a depth of several inches and partial leaching to a depth of two or three feet below the top of the calcareous zone. Because of the abundance of dolomite in post-Kansan tills in Illinois, the partially leached zone is still acid reactive, and generally it has not been differentiated. In the field, the dolomitic zone is recognized by relatively slow effervesence; in the laboratory, it is well shown by the X-ray diffraction analyses of the minus 2-micron size fraction (e.g., Chapin Section, P-2103).

Although the matrix (sand and finer materials) in the CL-zone is leached, carbonate pebbles were present in three of the five bulk samples from the zone (table 3). In general, the effect of greater solution (more rapid removal) of the finer sizes is to increase the percentage of the coarser sizes. This is shown by the samples from Fort Madison where the percent of carbonate pebbles in the incompletely leached sample (P-1289) increased nearly five times (5-24 percent) from the 2 to 8mm fraction but only two times (23-46 percent) in the calcareous sample (P-1288) below.

As would be expected, dolomite pebbles are proportionately more abundant among the pebbles surviving in the CL-zone. In the Hipple Section (Illinoian till), 30 percent of the carbonate pebbles in the calcareous till are dolomite, but 80 percent are dolomite in the CL-zone.

As previously noted (Frye, Willman, and Glass, 1960), the carbonates have peaks of abundance in the silt and pebble sizes because of the diluting effects of clay minerals in the clay fraction, of quartz grains in the sand fraction, and of igneous and metamorphic rocks in the cobble and boulder sizes. The bulk samples provide an opportunity to examine the distribution of carbonates in the pebble fractions.

The percentage of limestone and dolomite regularly increases through the 2, 4, and 8mm sizes in the samples from three of the six localities and in one sample from a fourth locality (table 6). At Hipple, the amounts are about the same in the 2, 8, and 16mm fractions but are lower in the 4mm size, where there is an unusually high percentage of chert. At Effingham, the percentage is erratic, and in one sample at Funkhouser, the order is reversed because of a progressive increase in abundance of chert.

The peak size appears to be in sizes coarser than those present in these tills in sufficient quantity to be significant. The decline in the percentage of quartz in the coarse sand is probably followed by a drop in the percentage of chert in fractions slightly larger than the maximum size present in these samples, and limestone and dolomite should have maximum abundance in those sizes.

Table 6. – Distribution of limestone and dolomite in pebble fractions of calcareous samples

	Funkhouser		Effingham			Fairview	Hipple	Donnellson	Fort Madison
	P-1286	1322	1276	1275	1274	1314	1317	1298	1288
mm.									
16	*	*	*	*	*	68	56	–	–
8	57	31	26	45	28	65	59	19	46
4	45	40	30	50	27	59	35	17	30
2	36	46	15	45	44	40	52	14	23

* Present but less than 25 pebbles in fraction

Sandstone and Siltstone

Sandstone and siltstone were combined in the counting because consistent differentiation seemed impractical. These materials are largely from the local bedrock of Pennsylvanian age, and a large amount falls close to the boundary line between siltstone and sandstone. The seven bulk samples of calcareous Illinoian till average 17 percent sandstone and siltstone in the pebble fractions, but the two Kansan till samples contained only about 8 percent.

Local derivation probably accounts for the fact that the vertical mixing of the sandstone and siltstone in the tills is not uniform, which is shown by the three calcareous samples at Effingham and the two at Funkhouser. At Effingham, the average percentages of the 2, 4, and 8mm fractions is 16, 7, and 15 (at the top), whereas at nearby Funkhouser, it is 23 and 15.

The amount of sandstone and siltstone is reasonably consistent in the individual fractions of each sample. Only 4 of 29 fractions of the calcareous samples were more than twice the minimum. There is no apparent tendency for greater abundance in coarser or finer fractions, so that abundance is not related to size control in a previously graded material.

In the sections of Illinoian till at Funkhouser and Fairview, the increase in percentage of siltstone and sandstone in the CL-zone is close to the increase that would be expected from solution of the limestone and dolomite pebbles (table 7). At Donnellson, the low percentage in the 8mm fraction in the CL-zone is an exceptional case of original variation, because the percentage is close to that anticipated in the immediately overlying sample in the base of the B-zone.

Table 7. - Comparison of the percentage of sandstone and siltstone in the CL-zone with the percentage that should be present calculated by removing carbonates from the CC-zone

	mm.	CC-zone	CL-zone	Calculated
Funkhouser	8	11	24	26
	4	17	33	31
	2	17	30	27
Fairview	8	10	47	28
	4	20	43	49
	2	21	43	35
Donnellson	8	13	2	16
	4	22	9	14
	2	2	1	2

The analyses at Funkhouser (table 3) are consistent enough to indicate the trend of changes in these constituents in the in-situ profiles. The decrease in abundance is slight in the base of the B-zone, but relative to the other constituents, except carbonates, the depletion averages 40 to 50 percent in the upper part of the B-zone. The decrease is distinctly greater in the coarser fractions. It apparently results from disaggregation by weathering. Many of the Pennsylvanian sandstones and siltstones are slightly calcareous, and these pebbles are probably broken down more readily than the others.

As pebbles commonly form 5 to 10 percent of the tills and 15 to 20 percent of the pebbles are sandstone and siltstone, disaggregation of these pebbles probably adds 1 to 2 percent to the clay, silt, and sand fractions.

In the three accretion-gley sections, the increase in the percentage of sandstone and siltstone in the leached and partially leached samples, immediately below the accretion-gley, conforms closely to the increase that should result from solution of the carbonates. The samples from the base of the accretion-gley, immediately overlying, have only a minor amount of these pebbles, in contrast to in-situ profiles where the basal B-zone sample shows only moderate decrease from the amount in the CL-zone (table 8). Further, these constituents are almost entirely lacking in the upper samples from the accretion-gley, although depleted only 40 to 50 percent in the upper B-zone samples. As chert and quartz persist in these fractions in the accretion-gleys, the decrease in sandstone and siltstone is explained best by weakening of the structural fabric of the pebbles by solution of calcareous cement during weathering in the in-situ position, followed by nearly complete disaggregation during transportation and later weathering in the accretion-gley.

At Donnellson the percentage of sandstone and siltstone in the CL-zone sample (table 8) is not consistent. The percentage in the calcareous till indicates that there should be 2, 14, and 16, rather than 1, 9, and 2 percent in the CL-zone, which is supported by the comparable quantity in the overlying sample from the base of the B-zone.

Shale

Shale is not an abundant constituent in the sand and pebble fractions of the tills. It is recorded with other light minerals in about half the sand fractions, but rarely is as much as 3 percent. In the pebble fractions, it is generally lacking,

Table 8. – Comparison of amounts of sandstone and siltstone in the in-situ and accretion-gley profiles

		Fraction (mm)					Fraction (mm)			
	Zone	2	4	8		Zone	2	4	8	16
Funkhouser	B	17	22	11	Effingham	G	–	–	–	
	B	34	31	18		G	–	–	–	
	CL	30	33	24		G	9	9	13	
	CC	17	17	11		CC	18	19	8	
Fairview	B	51	40	30	Hipple	G	2	4	5	*
	CL	43	43	47		G	2	–	5	10
	CC	21	20	10		CL	38	38	34	*
						CC	21	32	23	26
Donnellson	GB	2	8	*	Fort Madison	G	–	–	–	
	B	4	14	12		G	1	3	–	
	CL	1	9	2		CL	2	11	17	
	CC	2	12	13		CC	5	6	8	

* Present but less than 25 pebbles in fraction

except at Effingham where the percentage declines with increasing size from 8 percent in the 2mm fraction to 3 percent in the 8mm fraction. From 1 to 4 percent shale is recorded in about half the CL-zone samples, and except for a trace found in one sample, none is found in the B-, G-, and BG-zones. The clay fraction of the tills consists largely of clay minerals derived from shale. However, shale disaggregates so readily that it is only locally present in the sand and pebble fractions of the calcareous tills. Many of the more silty beds that are common in Pennsylvanian shales probably are classified as siltstone. The almost complete absence of shale in the B- and G-zones indicates complete disaggregation by weathering.

Chert

Chert reaches its peak of abundance relative to other constituents in the 4 and 8mm fractions in six of the nine bulk samples of calcareous till (table 9). Two of the peaks are in the 2mm fraction and one in the 16mm fraction. In terms of the whole sample, the peak is consistently in the 2mm fraction. From 15 to 30 percent of the pebbles in the eastern-derived Illinoian till are chert, but only about 10 percent are chert in the western-derived Kansan till.

In the sand, chert is only 1 to 4 percent of the .5mm fraction, and it averages only about 1 percent in the finer sand fractions. The abundance of quartz and feldspar sand grains results in the percentage of chert changing very rapidly from the dominant noncarbonate constituent in the 2mm fraction to a minor constituent in the .5mm fraction. The upward decline in relative abundance of chert begins in a size coarser than the coarsest size with enough pebbles to be counted, but from general observations, the proportion declines in coarser pebble fractions where limestone and dolomite dominate.

The chert in the tills is derived from several sources—gravel in which chert is sorted, residual soils in which the chert may retain original sizes and shapes, glacially eroded bedrock in which fracturing becomes a factor in size distribution, and silicification of limestone and dolomite pebbles during the development of the

Table 9. – Distribution of chert in calcareous samples

	Funkhouser		Effingham			Fairview	Hipple	Donnellson	Fort Madison
	P-1286	1322	1276	1275	1274	1314	1317	1298	1288
mm.									
16	–	–	*	*	*	16	12	–	–
8	16	26	37	21	28	8	10	16	13
4	23	21	33	20	47	12	21	16	7
2	24	17	28	25	27	14	11	5	5
.5	1	2	4	2	1	2	2	†	2
.25	†	–	†	2	1	–	2	†	†
.125	–	–	1	†	3	2	1	3	†
.062	†	3	2	–	†	1	1	1	1

* Present but less than 25 pebbles in fraction
† Present but less than ½ percent

soils. Consequently, the combination of irregularity in original size distribution, plus lack of uniformity in mixing, might be expected to result in major variations in abundance in the tills. The greatest local variation in the bulk samples is at Effingham where two calcareous samples average 22 and 34 percent chert in the pebble fractions. At Funkhouser, the two calcareous samples both average 21 percent. The effect of original variation seems to be shown largely in a lack of uniformity, or uniform trend, between individual samples. Nevertheless, the range of variations in individual samples is small. In five of the seven bulk samples of calcareous Illinoian till, the extremes in 21 of 23 fractions are not more than 5 percent in the actual measurements from the average.

The variation in the chert percentage in the weathered zone of the in-situ profiles is shown in table 10. The uniformity of the changes in the Funkhouser Section indicate a relatively high degree of original uniformity from the calcareous zone through the weathered zone. The increase in the percentage of chert pebbles in the CL-zone, as a result of solution of the limestone and dolomite pebbles, averages 19 percent, whereas the calculated result averages 18 percent. The increase in chert from the CL-zone to the upper part of the B-zone represents a depletion of 56 percent of the other constituents. If there is loss of chert by solution, which is not suggested by our data, the loss of other constituents would be even higher. The pebble fractions that have such a high depletion comprise only about 5 percent of the entire sample.

Table 10. – Distribution of chert in the in-situ profiles

	Funkhouser				Fairview				Donnellson			
Fraction (mm): Zone	2	4	8	Av.	2	4	8	Av.	2	4	8	Av.
B	54	57	66	59					15	34	–	25
B	30	44	62	45	31	36	54	40	12	26	24	21
CL	34	37	50	40	33	32	41	35	5	15	10	10
CC	24	23	16	21	14	12	8	11	5	16	16	12

In the Fairview Section, the chert in the CL-zone samples is higher than it should be, suggesting that the sample may overlap the base of the B-zone. The same effect would result if some of the limestone and dolomite was silicified during the leaching process. However, in by far the majority of samples, the percentage of chert in the CL-zone is close to the percentage calculated by removing the limestone and dolomite. As other evidence of silicification is lacking, this is a doubtful process in the soils under consideration. Variation in the original amount of chert is probably the major factor. Except for the 2mm fraction, the trend in the B-zone is the same as at Funkhouser, but the increase in percentage of chert is smaller.

The Donnellson Section differs from the Fairview Section in the opposite direction; the amount of the chert in the CL-zone is not as high as it should be. Otherwise, the variations in the Donnellson Section are entirely comparable to those in the Funkhouser Section, and the amounts of chert in individual fractions without exception fall in a consistent direction of change. The relative depletion of other constituents is nearly the same as in the Funkhouser Section—about 67 percent depletion of other materials in the GB-zone, compared with the content in the CL-zone.

The distribution of chert in the accretion-gley profiles is more erratic than in the in-situ profiles. Whereas the peak of abundance is in the top sample of the profile in all but one fraction of the in-situ samples, it falls in lower, middle, and upper samples of the accretion-gleys. Chert is proportionately higher in the accretion-gleys relative to other constituents, and it appears to be concentrated by selective transportation. The sharp increase in the basal accretion-gley sample, generally more than doubling in all sections, is different from the in-situ profiles where the change to the basal B-zone sample is relatively small.

The more erratic quantities in the accretion-gleys are in part related to the much smaller quantities of pebbles in the accretion-gleys than in the in-situ profiles.

Granite

The light-colored, coarse-grained igneous rocks, grouped for convenience under the general term granite, average about 3 percent of the pebbles in the bulk samples of calcareous Illinoian till and 17 percent in calcareous Kansan till (table 11). In the Illinoian till samples, the amount of granite is about equal in the 2 and 4mm fractions but averages 25 percent higher in the 8mm fraction. The peak of abundance of granite is in coarser fractions than represented in these samples, probably in the cobble or boulder fractions. Although the maximum percentage in any fraction is 6 percent, the quantities show an irregular variation between the fractions in each sample and in the same fraction in the different samples.

Table 11. – Distribution of granite in calcareous samples

	Funkhouser		Effingham			Fairview	Hipple	Donnellson	Fort Madison
	P-1286	1322	1276	1275	1274	1314	1317	1298	1288
mm.									
16	*	*	–	–	–	–	–	*	*
8	5	2	5	5	5	3	1	13	7
4	2	6	4	3	2	1	1	18	19
2	1	2	6	3	2	4	1	14	23

* Present but less than 25 pebbles in fraction

The lower size limit of granite as a recognizable rock that forms .5 percent or more is in the 1mm fraction in most samples. However, the 1 and 2mm fractions comprise a zone in which individual grains and pebbles of feldspar are abundant, as described under feldspar, and in many samples feldspar extends into the 4mm and even 8mm fractions (table 17). The granite pebbles are dominantly feldspar and in our analyses are differentiated from feldspar only by the presence of minor amounts of quartz, hornblende, or muscovite in the surface of the pebbles. The differentiation cannot be entirely consistent, which probably accounts for some of the irregularities in counts of both granite and feldspar. Disaggregation of the granites contributes to the feldspar content. In the pebble fractions, if the feldspar is added to the granite, it more than doubles the quantities in the 2mm fractions, but it adds less than one percent to the 4 and 8mm fractions.

The distribution of the granite in the in-situ profiles is well shown by the Funkhouser Section (table 12). The amount of granite in the CL-zone is close to the calculated percentage. In the lower part of the B-zone, there is a considerable depletion in the 8mm fraction, which may account for a relative gain in the 2mm fraction. The average for the sample shows about 10 percent depletion of granite in relation to the chert content. The depletion of granite in the upper part of the B-zone is about 50 percent, with much of the loss in the 2mm fraction. Granite pebbles of all sizes, including some in the 16mm fractions, are present in the upper part of the B-zone.

Table 12. - Distribution of granite in the Funkhouser Section

Fraction (mm): Zone	2	4	8	16
B	4	7	4	*
B	11	7	4	*
CL	3	4	9	*
CL°	2	4	12	
CC	1	2	5	*
Ls. & dol.	36	45	47	*

* Present but less than 25 pebbles in fraction
CL° Calculated from content in CC-zone

In the Fairview Section, the results are more erratic, as usual, but the average indicates essentially the same depletion as at Funkhouser. This suggests that the one sample from the B-zone represents the upper, more weathered part of the B-zone.

In the Kansan till at Donnellson, the distribution of the granite in the calcareous till is uneven and apparently is not representative of the original distribution of granite in the weathered zone. The amount of granite in the CL-zone is slightly less than should be present, and in the sample of the B-zone, there is a slight gain in granite relative to chert. The sample from the GB-zone shows a depletion of 92 percent in comparison to chert. Other evidence indicates that the upper part of the Kansan profile is more intensely weathered than the lower part. The absence of granite in the very small 8 and 16mm fractions of the GB-zone is consistent with its origin as a secondarily weathered accretion-gley derived from the uppermost part of the Yarmouth-Sangamon Soil.

In the uppermost samples in the accretion-gleys, a small percentage of granite is present in the 2 and 4mm fractions, but none is recorded in the 8 and 16mm fractions. As granite increases in abundance upwards, its absence in the coarser fractions appears to be related to the small quantities in these fractions, which is a result of sorting in transportation. Disaggregation of the larger pebbles is a contributing factor.

In the Effingham Section, the presence of about twice as much granite in the middle sample from the accretion-gley as in the lower sample is consistent with its origin as an accretion deposit. At Hipple, the granite pebbles are largely in the 8mm fraction in the lower accretion-gley sample, nearly the same as in the underlying leached till, but in the upper sample, the granite is largely in the 2mm fraction. At Fort Madison, granite is nearly as abundant in the lower accretion-gley sample as in the calcareous till, but it essentially disappears in the uppermost sample. This is not entirely the effect of weathering, because the same sample contains 13 percent of feldspar pebbles in the 2mm fraction.

Diorite

The dark-colored, coarse-grained igneous rocks are grouped under the general heading of diorite, but peridotite, gabbro, and similar types are included. These rocks average about 2 percent of the pebble fractions of the calcareous Illinoian till and 6 percent of the Kansan till. The percentage in the 8mm fraction is generally about twice as high as in the 2 and 4mm fractions, so that the peak of abundance is in coarser fractions. In a few samples, the 2mm fraction contains individual grains of hornblende so that, like granite and feldspar, the ranges of diorite and hornblende overlap in the coarsest sand and the small pebble fractions. However, the percentage of hornblende pebbles in the 2mm fractions does not exceed 1 percent.

In the in-situ weathering profiles on Illinoian till, the quantities of diorite are so small (less than 5 percent) that only general trends in changes seem significant. However, the pebbles of diorite are common in all three fractions in the upper B-zone sample in the Funkhouser Section, and the depletion relative to chert is only slightly higher than the depletion of granite.

In the Kansan till at Donnellson, the larger percentages permit a better evaluation (table 13). Relative to chert, 60 to 85 percent of the diorite is depleted in the B-zone sample. In the overlying GB-zone sample, the depletion is higher because diorite is lacking in the 8mm fraction, and 85 percent is depleted in the 2mm and 65 percent in the 4mm fractions. These analyses emphasize the high depletion of the less stable minerals in the uppermost part of the Yarmouth-Sangamon Soil profiles.

In the accretion-gleys, there is the usual variability. The basal sample from the accretion-gley at Effingham has essentially the same amount of diorite and the same size distribution as the underlying calcareous till, but there is almost no diorite in the two higher samples from the accretion-gley. In the Hipple accretion-gley, diorite is present only in the coarser fractions (8 and 16mm). At Fort Madison, diorite pebbles are largely lacking in the accretion-gley. In general, diorite pebbles are much less common in the accretion-gleys than in the in-situ profiles.

Felsite

The light-colored, fine-grained igneous rocks grouped under the general term felsite are too scarce in the Illinoian tills for recognition of a pattern in size distribution. Felsite averages less than 1 percent of the pebble fractions in all samples except 2 of 3 calcareous samples from the Effingham Section, where felsite is about 1 percent. In the western-derived Kansan till, however, felsite averages 1 percent in the 2mm fraction, 2 percent in the 4mm fraction, and 4 percent in the 8mm fraction, which suggests that felsite, like the other igneous and metamorphic rocks, is more abundant in coarser pebble fractions.

Table 13. – Distribution of diorite in the Donnellson Section

Fraction (mm): Zone	2	4	8
GB	1	4	-
B	1	5	4
CL	3	7	10
CL°	4	5	13
CC	3	4	11
Ls. & dol.	14	17	19

CL° Calculated from content in CC–zone

In the in-situ weathering profiles on Illinoian till, felsite is present in both B-zone samples at Funkhouser but is too scarce to be significant. At Donnellson, the distribution in the CL-zone is close to the calculated percentage. The loss in the B-zone sample is slight, but felsite is lacking in the GB-zone.

Felsite is present in the accretion-gley samples, but the quantity is small and scattered.

Basalt

The dark-colored, fine-grained igneous rocks, grouped under the general term basalt, include the dark green rocks commonly called greenstone. A consistent differentiation of these rocks by general appearance was not practical.

In the bulk samples of calcareous Illinoian till, basalt was consistently present, except there was only a trace in the lower of three samples from the Effingham Section (table 3). In the two higher samples, the pebble fractions contained about 5 percent basalt, which shows the potential range in original variations. Both the 2 and 4mm fractions average 3 percent basalt, and the 8mm fraction averages 4 percent with maximum amounts 6, 7, and 11 percent. Basalt increases in abundance in the coarser fractions, but more than other igneous rocks, it extends into the coarser sand fractions, where it is included in "other" grains.

Basalt is much more abundant in the western-derived Kansan till; the two samples average 11 percent in the 2mm fraction, 12 percent in the 4mm fraction, and 15 percent in the 8mm fraction.

The erratic distribution of these rocks in the in-situ profiles is related to irregular mixing in the till and to decomposition by weathering. The lack of uniformity in mixing probably results from combining different rock types from different source areas.

In the Illinoian till at Funkhouser, the decrease in abundance of basalt in the CL-zone, where it should increase, shows original variation, but the decrease in the B-zone samples indicates at least 50 percent depletion of the basalt in comparison to chert.

In the Kansan till at Donnellson, the extreme is greater (table 14). The amount of basalt doubles in the CL-zone, whereas, because of the low carbonates, it should increase no more than 20 percent. Nevertheless, the large decrease in abundance of basalt in the overlying B-zone sample appears to be a good measure of its depletion relative to chert because of the uniformity of the results—95 percent depletion of the 2mm fraction, 90 percent depletion of the 4mm fraction, and 89 percent depletion of the 8mm fraction. The extreme depletion of the basalt in the Yarmouth-Sangamon profile is further supported by the presence of only a trace of basalt in the uppermost GB-zone sample.

The amount of basalt in the accretion-gleys is similar to that in the in-situ profiles (table 14). There is a major upward decrease in abundance of basalt in the base of the accretion-gley, and the amount decreases upward so that very little remains in the uppermost samples. Basalt was absent in the upper sample of the Fort Madison accretion-gley. The inference is that the kinds of pebbles contributed to the accretion-gley changed with greater depth of weathering of the adjacent in-situ profiles, which favors the concept of slow accumulation of the accretion-gley through a major part of the interglacial stage.

Table 14. – Comparison of basalt distribution in the Donnellson and Fort Madison Sections

	Donnellson				Fort Madison		
Fraction (mm):	2	4	8		2	4	8
Zone				Zone			
GB	†	†	*	G	–	–	–
B	3	4	12	G	†	2	–
CL	21	24	44	CL	18	18	11
CL°	13	16	27	CL°	13	16	15
CC	11	13	22	CC	10	11	8
Ls. & dol.	14	17	19	Ls. & dol.	23	30	46

* Present but less than 25 pebbles in fraction
† Present but less than ½ percent
CL° Calculated from content in CC-zone

Quartzite

Quartzite pebbles are present in the 2mm fraction in only 2 of the 9 bulk samples of calcareous till. Quartzite as a constituent greater than .5 percent begins in the 4mm fraction, but it averages less than 3 percent in the 8mm fraction. Its peak of abundance is in coarser fractions than those represented in our samples.

The amount of quartzite is so low in the calcareous samples that no consistent change in abundance can be observed in the leached zones. The amount of quartzite is distinctly higher in the B-zones of the Funkhouser and Donnellson Sections, but lower in the Fairview Section. Nothing about the data suggests that quartzite differs from quartz in stability in the B-zone.

In the accretion-gley, quartzite pebbles are more abundant in the basal sample than in higher samples. The upper parts of the accretion-gleys contain relatively small quantities of the coarser fractions that contain more quartzite. The greater abundance of the coarser materials in the lower part of the accretion-gleys results from shorter distances of transport and steeper slopes than those during deposition of the upper part of the accretion-gley.

Schist and Gneiss

Pebbles of schist and gneiss are too scarce and too variable in composition to be useful in evaluating the degree of weathering. Their occurrence in the calcareous tills is erratic. In the Kansan till, pebbles of this type average 3 percent at Fort Madison. None were found in the calcareous till in the Donnellson Section, but 2 percent were present in the 8mm fraction in the CL-zone. Only a few pebbles of schist and gneiss were found in the Hipple and Fairview Sections, but they average about 2 percent in the Effingham Section. They appear to be types resistant to weathering, because a small percentage is persistently present in the 8mm fractions in the B-zones and in the accretion-gleys.

Quartz

Quartz reaches a peak of abundance in the .062mm fraction (very fine sand) in 4 of the 7 bulk samples of calcareous Illinoian till (table 15). The peak is in the .125mm fraction (fine sand) in two samples and in the .250mm fraction (medium sand) in one sample. The peak is exceptionally uniform, ranging from 70 to 74 percent. The peaks in the two Kansan till samples are in the .125 and .250mm fractions and are higher (81 and 86 percent) than in the Illinoian till. In all samples of Illinoian till, there is an abrupt decline in abundance of quartz in the .5mm fraction (very coarse sand), but in the Kansan till, the decline probably is in the 1mm fraction. The decline continues in the pebble fractions, and in the 2mm fraction, quartz averages only 7 percent in the Illinoian till and 19 percent in the Kansan till samples.

Table 15. – Distribution of quartz in calcareous samples

	Funkhouser		Effingham			Fairview	Hipple	Donnellson	Fort Madison
	P-1286	1322	1276	1275	1274	1314	1317	1298	1288
mm.									
16	–	–	–	–	–	–	–	–	–
8	–	2	5	–	1	6	1	1	1
4	3	1	5	2	2	4	6	13	11
2	7	5	16	9	3	5	7	27	12
.5	30	43	55	28	29	17	42	74	68
.250	70	71	70	69	70	55	70	86	79
.125	70	72	70	69	72	63	67	74	81
.062	71	68	63	74	74	74	69	77	77

There is a progressive change from dominantly clear, granitic-type quartz grains in the .5mm fraction to dominantly milky, vein-type quartz in the 2mm and coarser fractions. From the 2mm fraction, the decline in abundance continues into coarser fractions. The 8mm fraction represents essentially the maximum size of the quartz pebbles, because coarser fractions are present but lack quartz pebbles.

The quartz pebbles and the coarser sand grains are well rounded. The degree of rounding decreases in the finer sizes, comparable to the change in many Paleozoic sandstones. The fine and very fine sand is angular. The high degree of sorting also suggests that the quartz is largely derived from sediments.

Quartz pebbles are essentially stable in the weathered zone and their variations in the abundance largely result from removal of other constituents. The changes in percentage in the Donnellson Section are particularly uniform and consistent, as shown in table 16. The percentage in the CL-zone is close to the calculated percentage, which indicates an original uniform distribution throughout the weathered zone. The progressive decrease in percentage in coarser fractions is comparable to the decrease in the calcareous till. The increase in percentage upward in the profile is so close proportionately to the increase in chert that there is relatively no depletion of either.

The Funkhouser Section, which has remarkably consistent variations in abundance of most constituents, has an irregular distribution of quartz. The quartz shows a reverse trend from the chert—a smaller quantity in the B-zone than in the

Table 16. - Distribution of quartz in the pebble fractions of the in-situ profiles

Fraction (mm):	Funkhouser			Fairview			Donnellson		
Zone	2	4	8	2	4	8	2	4	8
GB							68	39	*
B	13	5	4						
B	16	11	4	11	16	3	36	20	8
CL	18	14	1	17	15	2	31	14	2
CC	7	3	0	5	4	6	27	13	1

* Present but less than 25 pebbles in fraction

CL-zone. The amount of quartz pebbles that should be present in the CL-zone, calculated from the percentage in the CC-zone, is about half the amount found in the CL-zone; if the calculated amount is used, the percentage of quartz in the B-zone indicates an increase in quartz. The increase, however, is still only about half that of the chert in the same samples, and it appears that quartz pebbles had an uneven distribution before weathering of the till.

In the Fairview Section, the distribution of quartz pebbles supports the general evidence of uneven mixing in the unweathered till that is indicated by nearly all other constituents. In the calcareous till, the amount of quartz increases with increasing size, but in the CL- and B-zones it decreases, as in other sections. Consequently, calculations of depletion based on distribution in the CC-zone are useless. Calculating in the opposite direction, the amounts in the 2, 4, and 8mm fractions in the CC-zone, instead of 5, 4, and 6 percent, should be 10, 6, and 1 percent.

The abundance of quartz pebbles in the accretion-gleys is generally comparable to that in the B-zones of the nearby in-situ profiles, although more irregular. All accretion-gleys have a large increase in abundance of quartz in the basal sample relative to the underlying till. In the Fort Madison Section, the upward increase is as uniform as in the in-situ profiles, but the relative increase in abundance is greater. It would require a much greater depletion of other constituents than otherwise indicated to increase the quartz pebbles from 12 percent in the 2mm fraction in the calcareous zone, which contains only 23 percent carbonates, to 66 percent in the uppermost accretion-gley sample. If this concentration is the effect of weathering, even the small amounts of quartz pebbles in the 8mm fraction in the CC- and CL-zones (1 and 3 percent) should be greatly accentuated in the accretion-gley, whereas they are entirely lacking. The absence of the coarser pebbles in the accretion-gley suggests sorting.

Feldspar

Feldspar averages about 20 percent of the material in the sand and pebble fractions of the calcareous tills. Although we have no counts of feldspar in the silt fractions, it is apparent from the trend of the variations in the sand fractions that the peak of abundance of feldspar falls in the silt size (table 17). X-ray analyses indicate that both potash and plagioclase feldspars are commonly present in the silt-size fraction of the tills although the analyses do not permit precise determination of the percentages.

Table 17. – Distribution of feldspar in calcareous till

	Funkhouser		Effingham			Fairview	Hipple	Donnellson	Fort Madison
	P-1286	1322	1276	1275	1274	1314	1317	1298	1288
mm.									
16						–			
8	–	–	–	2	1	–	–	–	–
4	–	–	1	1	1	1	–	4	4
2	7	4	4	3	2	8	4	24	12
.5	13	22	21	14	19	5	7	11	24
.250	10	19	16	15	19	6	14	6	14
.125	23	18	22	22	24	20	18	17	18
.062	23	25	28	23	20	20	21	20	21

In the sand fractions of the bulk samples, feldspar is generally least abundant in the medium sand, where quartz is at its peak. The sharp decline in amount of feldspar from sand to pebbles in many samples results largely from increasing abundance of limestone and chert in the pebble fractions.

Feldspar commonly has its limit as individual grains in the smallest pebbles (2mm fraction), in which granite, largely feldspar, becomes common. Although granite is generally less than 6 percent of the pebble fractions in the Illinoian till samples, it is an abundant constituent of the Kansan till samples (table 18). Granite probably accounts for a marked increase in abundance of feldspar in the pebble fractions, because the line between the two is not easily drawn. Granite plus feldspar is nearly twice as abundant in the pebble fractions as in the sand in the Kansan till, and three to five times as abundant as in the pebble fractions of the Illinoian till.

Table 18. – Distribution of feldspar and granite in calcareous till in the Funkhouser and Fort Madison Sections

	Funkhouser		Fort Madison	
mm.	Granite	Feldspar	Granite	Feldspar
16	*		†	
8	5		7	
4	2		19	4
2	1	7	23	12
.5		13		24
.250		10		14
.125		23		18
.062		23		21

* Present but less than 25 pebbles in fraction
† Present but less than ½ percent

Potash feldspars are commonly 20 to 30 percent more abundant than the soda-lime feldspars in the medium and finer sand fraction, but the soda-lime feldspars are more abundant than potash feldspars in seven of the nine samples of coarse sand.

In the in-situ profiles, feldspar is depleted relative to quartz and chert much less than are other rocks and minerals. In all samples, the loss is greater in the coarser fractions than in the finer fractions. There is no great difference between the losses of potash feldspar and soda-lime feldspars, suggesting that most of the feldspars have been through several cycles of sedimentation and are of the more stable types.

In the Funkhouser Section (table 19), feldspar depletion relative to quartz averages 13 percent in the lower B-zone sample and 25 percent in the upper sample. In the Kansan till at Donnellson, the depletion of feldspar appears to be very slight in the B-zone sample, but depletion averages about 40 percent in the upper GB-zone sample. In the minus 2-micron fraction, feldspar is present in the B-zone sample but was not detected in the GB-zone sample.

Table 19. - Distribution of feldspar in the sand fractions of the Funkhouser and Donnellson Sections and depletion of feldspar relative to quartz

Fraction (mm):	.062		.125		.250		.5	
Zone	%	% Dep.	%	% Dep.	%	% Dep.	%	% Dep.
Funkhouser								
B	23	10	20	28	15	35	18	29
B	28	0	19	28	19	14	22	9
CL	26		26		20		22	
CC	23		23		10		13	
Donnellson								
GB	17	25	12	34	10	37	7	58
B	17	26	21	0	16	0	20	0
CL	22		17		14		13	
CC	20		17		6		11	

Feldspar occurs in the accretion-gleys in amounts approximately the same as in the in-situ profiles but with more irregular distribution. In the Hipple Section, feldspar is more depleted in reference to quartz in the lower part of the accretion-gley than in the upper, in contrast to the Effingham and Fort Madison Sections where the greatest depletion is in the upper part of the accretion-gley.

In the Effingham Section, the feldspar pebbles show a gain in abundance relative to chert pebbles in the upper two accretion-gley samples—the feldspar in the 2mm fraction increases from 4 percent in the CL-zone and the basal accretion-gley sample to 13 percent in the middle sample and to 20 percent in the upper. In the 4mm fraction, there is a comparable increase from 1 to 5 and 11 percent. On the contrary, the feldspar pebbles are depleted relative to chert by about 85 percent in the upper Fort Madison sample. Much of the feldspar in the accretion-gleys is somewhat weathered, but many grains are fresh and sharp. In spite of the variability, there clearly is no greater depletion of feldspars in accretion-gleys than in the in-situ profiles.

Heavy Minerals

Heavy minerals commonly form 1 to 3 percent of the three fractions from which separations were made (table 4). In the calcareous till samples, the range is from 0.88 percent to 3.44 percent (table 20). The percentage increases in the finer sizes, usually doubling from the medium to very fine sand. The quantity is about the same in the eastern-derived Illinoian till as in the western-derived Kansan till.

The heavy-mineral suites consist of about 50 percent opaque minerals and 50 percent transparent and translucent minerals, which are called transparent for convenience. In the table of mineral analyses (table 4), the opaque minerals, which are differentiated only as "black" and "others," are reported in percentage of the entire heavy mineral suite, but the transparent minerals are reported in percentage of total transparent minerals.

Table 20. – Percentage of heavy minerals in sand fractions of calcareous tills

	Funkhouser		Effingham			Fairview	Hipple	Donnellson	Fort Madison
	P-1286	1322	1276	1275	1274	1314	1317	1298	1288
mm.									
.250	.96	1.32	1.76	1.62	1.54	2.10	1.50	0.97	0.88
.125	1.56	1.92	2.06	2.11	1.78	2.20	1.83	1.36	1.42
.062	1.96	2.00	3.44	2.40	3.08	0.92	1.08	1.86	1.83

Opaque Heavy Minerals

The black opaque minerals are largely magnetite and ilmenite. The "other" opaque heavy minerals include grains of all colors except black and are referred to as light-colored. They consist of a variety of nondescript grains, many of which appear to be alteration products of normally transparent heavy minerals. Some are leuxocene. Many of them look like very fine-grained aggregates. The general consistency of the percentages of both black and light-colored opaque grains suggest that they are generally primary constituents and not secondary. However, at Hipple, the large increase in percentage of opaque heavy minerals in the basal sample from the accretion-gley (5 to 10 times the normal percentage) suggests a secondary origin.

The black opaque minerals comprise only about 3 percent of the heavy minerals in the medium sand, but they average 19 percent in the very fine sand (table 21). The abundance of light-colored or "other" opaque minerals varies in the opposite direction from the black grains—most abundant in the medium sand, less than half as much in the very fine sand. Because of the greater abundance of the light-colored opaque grains, the total opaque minerals decreases from two-thirds of the entire suite in the medium size to less than one-half in the very fine size.

Table 21. – Average percentages of opaque heavy minerals in 9 bulk samples of calcareous till

Fraction	% H.M.	Black	Others	Total
mm.				
.250	1.26	3	61	64
.125	1.80	8	42	50
.062	2.06	19	25	44

The uniformity in distribution of the opaque minerals in the calcareous samples is exceptionally high. The percentage of black opaque grains in the three fractions in all 9 samples increases progressively to the very fine fraction, and only in one fraction was the amount of the light-colored opaque minerals not consistent with the reverse trend.

In the Illinoian till at Funkhouser, the amount of opaque minerals shows a slight increase in the B-zone sample over the amount in the CC- and CL-zones (table 22). Depletion of the transparent minerals, therefore, is only slightly higher than depletion of the opaques. On the other hand, in the more deeply weathered Kansan till at Donnellson, total opaque grains show an increase of 15 to 20 percent in the B- and GB-zones, which indicates a much greater depletion of the transparent minerals. The actual loss is even greater, because the total percentage of heavy minerals decreases in the B-zones in the Illinoian till to about half the amount in the calcareous Illinoian till and to about one-third in the calcareous Kansan till. In these profiles, the opaque minerals appear to be among the more stable minerals.

Table 22. – Distribution of opaque heavy-mineral grains in the Funkhouser and Donnellson Sections

		Funkhouser		Donnellson	
Fraction (mm)	Zone	% H.M.	Opaque	% H.M.	Opaque
.250	GB			0.30	78
	B	0.41	57		
	B	0.38	49	0.56	63
	CL	0.72	50	0.99	63
	CC	0.96	54	0.97	58
.125	GB			0.44	58
	B	0.88	35		
	B	0.61	38	0.75	50
	CL	1.51	28	1.31	46
	CC	1.56	41	1.36	50
.062	GB			0.76	57
	B	1.19	39		
	B	1.24	27	0.97	51
	CL	2.48	28	1.64	47
	CC	1.96	27	1.86	40

In the accretion-gleys, the opaque minerals are much more variable in abundance than in the in-situ profiles (table 23). The general tendency for the opaque minerals to be much less abundant in the accretion-gleys than in the in-situ profiles (table 22) apparently is a sorting effect. The opaque minerals average higher in specific gravity than the transparent minerals.

Tourmaline and Zircon

The two most stable heavy minerals, tourmaline and zircon, are present generally in only small amounts in the calcareous bulk samples. Tourmaline averages about 1 percent of the transparent heavy minerals in each of the three sand fractions. Zircon was not reported in the medium sand and is only 1 percent in one-third of the fine sand fractions, but it averages 7 percent in the very fine

Table 23. – Distribution of opaque heavy minerals in the accretion-gleys

Fraction	Zone	Effingham % H.M.	Effingham Opaque	Hipple % H.M.	Hipple Opaque	Fort Madison % H.M.	Fort Madison Opaque
mm.							
.250	G	0.08	37				
	G	0.29	19	0.35	63	Tr	64
	G	0.32	29	4.56	86	0.17	48
	CL			1.98	82	0.78	59
	CC	1.76	86			0.88	59
	U	1.62	69	1.50	65		
.125	G	0.44	16				
	G	0.56	18	0.63	50	0.35	55
	G	0.76	19	4.78	68	0.49	40
	CL			2.08	62	1.09	51
	CC	2.06	50			1.42	46
	U	2.11	49	1.83	62		
.062	G	1.18	28				
	G	1.73	34	1.00	48	0.65	52
	G	1.50	28	3.10	64	0.77	36
	CL			1.18	58	1.43	53
	CC	3.44	54			1.83	39
	U	2.40	50	1.08	58		

sand, ranging from 1 to 22 percent. The peak abundance of zircon is probably in the silt fraction in most samples.

In the Kansan till at Donnellson (table 24), tourmaline increases 3 to 5 times from the CL-zone to the top of the GB-zone in all three fractions, and zircon increases a comparable amount in the very fine sand fraction, which indicates a depletion of about 75 percent of all the other transparent heavy minerals at the top of the profile. In the Illinoian till, at Funkhouser the increase is smaller and less regular, but it indicates a depletion of about 50 percent of the other minerals.

Table 24. – Distribution of tourmaline and zircon in the Funkhouser and Donnellson Sections

	Funkhouser						Donnellson					
	Tourmaline			Zircon			Tourmaline			Zircon		
Fraction: Zone	.062	.125	.250	.062	.125	.250	.062	.125	.250	.062	.125	.250
GB							5	5	8	15	2	–
B	–	1	2	17	2	1						
B	1	3	1	7	–	–	1	6	3	7	–	–
CL	1	2	1	3	1	–	2	1	1	5	1	–
CC	1	–	–	5	–	–	–	–	–	8	1	–

The slight upward increase in tourmaline and zircon in the in-situ profiles on Illinoian till is reflected in the accretion-gleys, which show no significant differences. The Fort Madison accretion-gley shows the influence of the considerably greater depletion of other minerals in the in-situ profiles by a comparable increase of tourmaline and zircon in the top of the accretion-gley.

Tourmaline is too scarce and unevenly distributed to be satisfactory as a reference mineral for calculating depletion of the less stable minerals. Zircon is also unsatisfactory for these reasons in the medium and fine sand. However, in the very fine sand fraction in many of the samples, zircon is abundant enough to serve as a stable reference mineral.

Garnet

Garnet is consistently present in the transparent heavy-mineral suite and moderately uniform in abundance in the three sand fractions analyzed, averaging 16 percent in the medium sand, and 18 percent in both fine and very fine sand. In six of the seven bulk samples of calcareous Illinoian till, garnet increases in abundance in the finest size. In the two Kansan till samples, the garnet is more abundant in the medium fraction. The distribution in individual localities (table 25) indicates that garnet is somewhat less regular in distribution than epidote (table 27).

Table 25. - Distribution of garnet in calcareous tills

	Funkhouser		Effingham			Fairview	Hipple	Donnellson	Fort Madison
	P-1286	1322	1276	1275	1274	1314	1317	1298	1288
mm.									
.250	22	23	21	13	15	20	8	12	8
.125	26	29	18	22	10	18	12	11	19
.062	30	19	12	26	18	26	20	6	5

In the in-situ profiles, garnet generally increases in percentage in the B-zones because of the depletion of other minerals, especially hornblende. However, this increase is not as great as the increase in epidote, which appears to be more stable, and indicates there is a relative loss of garnet. In the in-situ profile at Funkhouser, garnet increases in the lower B-zone sample but decreases in the upper sample, indicating that garnet loss becomes greater relative to the other minerals in the more weathered zone at the top of the profile.

There seems to be no significant differences in proportion of loss between the different size fractions, and averages of the fractions were used to calculate approximate amounts of depletion. Although the percentage of garnet increased about 25 percent in the B-zone in the Funkhouser Section, the depletion of garnet relative to epidote is 35 percent. A similar depletion was calculated for the Fairview Section where the results, as usual, are more variable. In the Donnellson Section, garnet increases about 50 percent in the B-zone, but the depletion relative to epidote averages only about 15 percent. Compared to zircon (table 26), the loss of garnet may be as much as 75 percent in the more intensely weathered GB-zone.

In the accretion-gleys, the percentage of garnet is commonly double the amount in the calcareous tills below, and it is relatively higher than in the B-zones of nearby in-situ profiles. Garnet seems to persist somewhat better in the

Table 26. – Percent depletion of garnet relative to zircon in the very fine sand fraction in the Funkhouser and Donnellson Sections

	Funkhouser			Donnellson		
Zone	Zircon	Garnet	Garnet Depletion	Zircon	Garnet	Garnet Depletion
GB				15	9	75
B	17	36	78			
B	7	37	48	7	18	0
CL	3	30		5	12	
CC	5	30		8	6	

accretion-gleys than does epidote. Although garnet shows a slightly greater depletion than epidote in the medium and fine sand fractions from the Effingham accretion-gley, epidote is depleted relative to garnet in the very fine-sand fractions in all three samples. Maximum depletion of garnet relative to epidote is in the very fine sand fraction of the Fort Madison accretion-gley where nearly 75 percent of the garnet is depleted, which is slightly greater than in the same fraction from the GB-zone at Donnellson.

The general similarity of garnet distribution in the accretion-gleys to that in the B-zones is consistent with derivation of the accretion-gleys from the in-situ soils adjacent to them.

Epidote

Epidote is much more abundant than garnet in calcareous Kansan till, but garnet is more abundant than epidote in Illinoian till (table 27). This difference has proven useful in differentiating the eastern- and western-derived tills (Willman, Glass, and Frye, 1963). Although garnet is fairly evenly distributed in the sand fractions analyzed, the abundance of epidote is closely related to grain size. In both Illinoian and Kansan tills, epidote is from 2 to 5 times more abundant in the very fine sand than in the medium sand. The peak of abundance of epidote may fall in the silt fraction.

Table 27. – Distribution of epidote in calcareous tills

	Funkhouser		Effingham			Fairview	Hipple	Donnellson	Fort Madison
	P-1286	1322	1276	1275	1274	1314	1317	1298	1288
mm.									
.250	6	3	–	4	1	5	6	10	8
.125	2	2	6	5	3	13	9	16	5
.062	8	12	12	11	7	19	12	27	24

Although epidote is a relatively stable mineral in these profiles, it may be depleted to a considerable extent in the uppermost part of the B-zones, as shown in the Funkhouser Section where the percentage of epidote decreases in the uppermost B-zone sample in the very fine sand fraction. In this fraction only is there enough zircon to serve as a basis for comparison (table 28). Relative to zircon, epidote is depleted 62 percent at the top of the Funkhouser Section and 41 percent in the GB-zone at the top of the Donnellson Section. As garnet shows a loss relative to zircon of 75 percent in the same samples, epidote by this comparison is more resistant to weathering than garnet.

Table 28. - Depletion of epidote relative to zircon in the very fine sand fractions of the Funkhouser and Donnellson Sections

	Funkhouser			Donnellson		
Zone	Zircon	Epidote	Epidote Depletion	Zircon	Epidote	Epidote Depletion
GB				15	33	41
B	17	15	62			
B	7	18	0	7	41	0
CL	3	7	0	5	18	0
CC	5	8	0	8	27	0

Epidote is more abundant in the Fort Madison and Hipple accretion-gleys than in the nearby in-situ profiles, but approximately the same in the Effingham Section. The increases are in the very fine sand fraction, and the small decrease in the medium sand fraction may be a slight sorting effect.

Rutile

Rutile is relatively uncommon among the transparent heavy minerals in these samples. It is reported in only 13 of 78 fractions analyzed, and as much as 2 percent was found in only two fractions. Rutile is present in all three size fractions but is most commonly reported in the very fine sand fraction. Its presence in the B-zone and accretion-gley samples is consistent with its recognition as one of the more stable minerals.

Staurolite, Kyanite, Andalusite, Sillimanite

These metamorphic minerals are too scarce in the tills generally to be useful in evaluating weathering. Minerals in this group are represented in only 6 of the 9 calcareous samples. They are reported in some samples from the weathered zones where they were not found in the underlying calcareous till. They are more abundant in the western-derived Kansan till than in the Illinoian till.

Staurolite is by far the most abundant, and its concentration in the B- and GB-zones of the Donnellson Section shows its high resistance to weathering. As the increase is proportionately much higher than the increase in zircon, it is probable that the amounts recorded in the calcareous till are much lower than normal, which is also suggested by other analyses of the western Kansan till. Nevertheless, the presence of 10 to 13 percent staurolite at the top of the profile, in contrast to only 4 percent in the lower part of the B-zone, indicates the much greater depletion of other minerals and suggests that it is about as resistant as zircon in the conditions represented by these soils.

Hornblende

Hornblende is the most abundant of the transparent heavy minerals in the sand fractions of the calcareous tills. It forms more than 50 percent of the suite in all but 3 of 27 sand fractions (table 29). Uniformity of distribution is best shown by the calcareous samples at Effingham and Funkhouser.

Table 29. – Distribution of hornblende in calcareous samples

	Funkhouser		Effingham			Fairview	Hipple	Donnellson	Fort Madison
	P-1286	1322	1276	1275	1274	1314	1317	1298	1288
mm.									
.250	57	62	79	69	71	70	76	67	73
.125	61	62	70	61	74	59	65	70	66
.062	49	56	62	56	65	36	40	52	55

Hornblende is most abundant in the medium-sand fraction, averaging 69 percent. The fine sand fraction averages 65 percent, and the very fine sand averages 52 percent. Although the silt fractions were not counted, the abundance of hornblende in the very fine sand suggests that hornblende is an abundant constituent in the silt. In some samples, it probably is as much as 50 percent of the transparent heavy minerals of the coarser silt fractions.

The peak of abundance of hornblende is in the medium sand size in 6 of 9 bulk samples. Hornblende continues into coarser sand fractions, and in some samples, it may be more abundant in the coarse or very coarse sand fractions, which were not counted. As much as 1 percent of hornblende is present in the 2 and 4mm pebble fractions of several samples. This is approximately the same as the percentage in the sand fractions as a whole.

There is no apparent depletion of hornblende in the CL-zone samples of the in-situ profiles (table 30). However, the bulk CL-zone samples commonly represent about the middle of the zone, and some loss of hornblende in the upper few inches would not be shown by these samples. The small variations between the CC- and CL-zones in the bulk samples is not more than normal variation in the deposits, with the exception of the Fairview Section where the increase of about 20 percent in the CL-zone is in the reverse direction and further indicates the variation in original composition in the deposit.

Table 30. – Depletion of hornblende in the Funkhouser and Donnellson Sections

Fraction (mm)	.062			.125			.250		
		Depletion relative to			Depletion relative to			Depletion relative to	
Zone	Hornblende	Epidote	Zircon	Hornblende	Epidote	Zircon	Hornblende	Epidote	Zircon
Funkhouser									
B	28	72	87	38	80	84	52	70	78
B	34	72	64	53	55	48	62	0	37
CL	56			56			58		
CC	49			61			57		
Donnellson									
GB	26	68	89	34	76	82	33	79	89
B	31	68	68	42	73	65	51	54	60
CL	55			66			78		
CC	52			70			67		

The upward depletion of hornblende in the B-zones is well shown by two bulk samples from the Funkhouser Section. However, the lower of the B-zone samples covers a thick enough interval that it does not show the very small depletion in the basal few inches of the zone, as previously described (Frye, Willman, and Glass, 1960). At Funkhouser, hornblende appears to be depleted by 50 to 60 percent in the lower B-zone sample and by 75 to 80 percent in the upper sample (table 30). In comparison, the depletion of hornblende in the Kansan till at Donnellson is 60 to 65 percent in the B-zone sample and 75 to 85 percent in the higher GB-zone sample. The depletion of hornblende is based on comparison with the epidote in the same fractions and with zircon, using the percentages of zircon in the very fine sand fraction. The average of the amounts in the CC- and CL-zones was used in calculating the depletion. With the exception of the zero depletion in the medium sand fraction at Funkhouser, which results from an abnormally low epidote content in the fraction, the results show a close correlation in the lower B-zone sample. In the upper samples, the higher depletion in relation to zircon is probably more accurate. The lower depletion in relation to epidote is consistent with other evidence that epidote is also lost in the uppermost part of the B-zones.

In the accretion-gley sections, the depletion of hornblende is comparable to that in the B-zones, but more erratic. The uppermost sample from the accretion-gley at Fort Madison shows the maximum loss of hornblende in relation to zircon: 92, 93, and 95 percent in the three fractions. Variations within the accretion-gleys are shown best by the closely spaced samples previously reported (Frye, Willman, and Glass, 1960).

Hypersthene

Hypersthene is present in all but five of the heavy-mineral suites from the bulk samples, but the amount is small. It averages about 3 percent of the transparent heavy minerals in the medium sand, 2 percent in the fine sand, and 1 percent in the very fine sand. The maximum for any fraction was 6 percent. The quantities are too small, and the distribution not uniform enough to warrant definite conclusions about its resistance to weathering, but it appears to be one of the moderately stable minerals and much more stable than hornblende.

In the Donnellson Section, hypersthene is more abundant in both the B-zone and GB-zone samples than in the CL- and CC-zone samples, whereas hornblende decreases from about 70 percent in the calcareous samples to 35 percent in the GB-zone. The presence of 3 percent hypersthene in the upper accretion-gley sample at Fort Madison is particularly indicative of high stability because of the high depletion of epidote and garnet in the same sample. At Funkhouser and Fairview, hypersthene has about the same abundance in the B-zone as in the CC- and CL-zones, which would indicate some loss in weathering because of the large depletion of hornblende. Only at Effingham is the percentage in the accretion-gley much lower than in the till below. However, the abundance of hypersthene in the lower two calcareous samples is not supported by its scarcity in the upper calcareous sample, and the accretion-gley may be derived from material generally lower in content of hypersthene.

Augite and Diopside

Augite and diopside, combined in the analyses, are minor constituents in the tills, averaging 2 percent of the transparent heavy minerals of the medium-size fraction, about 1½ percent of the fine size, and 1 percent of the very fine size. They appear to be even more readily weathered than the hornblende, which probably accounts for their scarcity in the calcareous samples. In the Illinoian till at Funkhouser, 4 to 6 percent augite and diopside is reported in the calcareous samples, but only 1 percent in the lower B-zone sample and none in the upper. In the Kansan till at Donnellson, 2 to 3 percent is present in the calcareous and leached till, none in the B-zone or GB-zone samples.

Actinolite and Enstatite

Actinolite and enstatite average less than 1 percent of the transparent heavy minerals in the calcareous tills. They are more abundant in the medium-sand fraction than in the fine and very fine fractions. Both minerals are present in the CC- and CL-zones in the Funkhouser Section, but only enstatite is reported in the B-zone samples (in the fine and very fine fractions), suggesting its greater resistance to weathering.

SUMMARY OF MINERALOGICAL DATA

The mineral compositions of the unaltered glacial tills in Illinois are described in the first part of this report (Willman, Glass, and Frye, 1963). The data presented here on the mineral compositions of weathering profiles in the tills are based on intensive studies of selected localities and supplement the data previously presented (Frye, Willman, and Glass, 1960). The genetic interpretations summarized previously (Frye, Willman, and Glass, 1960, p. 5, 19) are strongly supported by these data and are not entirely re-stated here.

The typical Illinoian till sampled in this study has a mineral composition approximately as shown in table 31. This compilation is based on projections from the compositions of the fractions analyzed. The major loss of volume resulting from weathering is by solution of the carbonates, which causes a shrinkage of 20 to 25 percent. The effect of loss of the carbonates is shown best in the CL-zone where other changes are relatively minor. The effect on grain size is greater in the pebble fractions than in finer fractions, which contain smaller and more nearly uniform proportions of carbonates. Although half the pebbles are carbonates, the effect of their solution is not great, because pebbles form only about 10 percent of the till. The overall effect preserves about the same texture as in the calcareous till, and the leached zone has a typical till appearance.

By far the greater change in appearance is between the CL-zone and the B-zone. The change in the B-zone results largely from modification of the till fabric by physical processes accompanied by alteration of some of the clay minerals to other clay minerals, by the addition of clay minerals by illuviation, and by a minor addition of clay minerals from decomposition of silicates. The increase in amount of clay is relatively slight in the lower part of the B-zone, and the appearance of greater abundance of clay results largely from the change of the clay to a more plastic type. There is no evidence of a significant loss of volume in this zone other than the loss of carbonates.

If the clay increase in the B-zone resulted largely from decomposition of silicates, as advocated by the gumbotil interpretation, a significant loss in volume would be required. The total amount of silicate minerals in the unaltered tills, other than clay minerals, is only about 15 percent. As there is only slight loss of these minerals in the lower part of the B-zone, decomposition of silicates cannot be the cause for the distinctive characteristics of the B-zone. Decomposition of the non-clay silicates is relatively high at the top of the B-zone and in the A-zone of the soils developed on the pre-Wisconsinan tills. The clay formed by this process, as well as the altered original clay, moves downward and enriches the B-zone.

Table 31. – Estimate of mineral composition of typical unaltered Illinoian till

	Boulders and Cobbles (1%)	Pebbles (9%)	Sand (35%)	Silt (35%)	Clay (20%)	Average %
Limestone and Dolomite	30	45	20	25	15	23.1
Sandstone and Siltstone	8	15	1			1.8
Shale		2	1	1		.9
Chert	1	18	2	1		2.7
Granite	25	5				.7
Diorite	10	2				.3
Felsite	4	1				.1
Basalt and Greenstone	12	3				.4
Quartzite	5	1				.1
Schist and Gneiss	5	1				.1
Quartz		7	60	55	15	43.9
Feldspar			14	16	8	12.1
Heavy Minerals			2	2	1	1.6
Illite					36	7.2
Montmorillonite					10	2.0
Kaolinite and Chlorite					15	3.0

The western-derived Kansan till is represented by only two bulk samples of calcareous till, but its composition differs in several significant constituents from that of the eastern-derived Illinoian till. It contains only about half as much carbonates, and limestone is more abundant than dolomite, which contrasts with dolomite domination in the Illinoian till. Among the clay minerals, montmorillonite, rather than illite, is dominant. The Kansan till is distinguished from the Illinoian till also by containing less sandstone, siltstone, quartzite, chert, and garnet and by containing more granite, diorite, basalt, felsite, epidote, and staurolite. These differences are important in identification of the two tills in their area of overlap in western Illinois. The greater abundance of montmorillonite in the western-derived till may account in part for the thicker plastic zones in the Yarmouth profiles.

Grain Size

In the in-situ profiles, the vertical variation in grain size is related, in order of magnitude, to (1) leaching of carbonates, (2) clay enrichment by illuviation from decomposition of silicates and from pre-existing clay minerals, (3) disaggregation of rock fragments, and (4) in-situ decomposition of silicates decreasing downward through the B-zone.

In the accretion-gleys, grain size is primarily related to (1) materials on the till surface before deposition of the accretion-gley, (2) degree of weathering on the surrounding till slopes, (3) gradients of the slopes, and (4) minor modifications by weathering after deposition.

The unaltered till is about 1 percent cobbles and boulders, 9 percent pebbles, 35 percent sand, 35 percent silt, and 20 percent clay. This composition is typical of many of the tills of Illinois, but the tills range from this composition to tills with more than 50 percent in any of the above fractions.

Because the effect of weathering on grain size is predictable, grain size is useful in evaluating the degree of uniformity of the deposit before it was weathered. Grain size may indicate, in extreme cases, that beds of gravel, sand, silt, or clay on the surface of the till were modified or mixed in the weathering process.

Grain-size analyses show a gradational change through the in-situ profiles, in contrast to a sharp upward increase in clay content at the base of the accretion-gleys. In some cases, the analyses show an erosional lag concentrate of coarse material on the till surface before deposition of the accretion-gley.

The major fractions of the tills—gravel, sand, silt, and clay—each have a characteristic size that gives the tills a strongly multi-modal size distribution. Grain size shows an original source in pre-existing sediments. The distinctive size distribution persists through the most weathered parts of the in-situ profiles. Weathering has not advanced to an extreme degree where the characteristic grain-size distribution is destroyed.

Clay Minerals

The clay minerals of the unaltered tills consist of illite, montmorillonite, kaolinite, and chlorite. Those tills derived from the northwest contain predominantly montmorillonite and kaolinite with minor amounts of illite, and those from the northeast contain predominantly illite with minor amounts of chlorite and kaolinite.

In the in-situ profiles, clay minerals are altered by weathering of a predominantly destructive type. That is, the changes are generally gradational, illite and chlorite altering to expandable types of clay minerals with intermediate mixed-lattice types. The alteration of chlorite to vermiculite is the most rapidly achieved and proceeds to depths in the profile comparable to the depth of recognizable oxidation (CC-zone). Upward in the profile with more intensive weathering, vermiculite is altered to more expandable forms, and when it expands to essentially 17Å with ethylene glycol, a heterogeneous swelling clay material (B-clay) results. This heterogeneous swelling material is here differentiated from homogeneous swelling montmorillonite, even though it is included by many workers within the general term montmorillonite. Chlorite is generally eliminated from the A- and B-zones of Sangamon and Yarmouth Soils, but it is recognizable as vermiculite in the B-zones of soils developed on Wisconsinan tills.

In the in-situ Sangamon and Yarmouth Soils, the alteration of illite extends downward into the uppermost part of the CL-zone. Upward through the B-zone, increasing intensities of alteration produce mixed-layer material and, finally, the heterogeneous swelling material (B-clay) that is indistinguishable from similar material derived from chlorite. A significant amount of illite remains in these B-zones even though chlorite is eliminated. In soils developed on Altonian tills, illite loss extends downward only into the B_2-zone, and in those on Woodfordian tills, illite loss is not detectable in the B-zones.

Alteration of montmorillonite in the in-situ profiles is detectable only by a broadening of the 17Å diffraction peak, which, when sufficiently broad, is indistinguishable from that of heterogeneous swelling material derived from chlorite and illite.

Kaolinite appears to be essentially unchanged throughout these profiles. Goethite is generally present in the in-situ profiles but is absent in the accretion-gleys.

Accretion-gleys are derived from slightly weathered to the most intensely weathered materials on the adjacent gentle slopes. Sheet-wash down these gentle slopes into shallow depressions or very poorly drained areas results in deposition of the accretion-gley on a surface of slightly to strongly weathered till. Therefore, clay-mineral alterations observable in an accretion-gley profile are of two distinct types. In the till below the accretion-gley, the sequence of clay-mineral alterations resembles that in the lower part of an in-situ profile. However, at the contact of accretion-gley on the weathered till, a sharp discontinuity in clay-mineral assemblages occurs.

The clay-mineral assemblages of the accretion-gley result from constructive pedogenic processes in contrast to destructive processes in the B-zones of the in-situ profiles. That is, the formation of vermiculite and homogeneous swelling montmorillonite from degraded materials brought into the reducing environment of the accretion-gley differs markedly from the gradual elimination of vermiculite and some illite and the development of heterogeneous swelling material—the degraded end-product of clay-mineral alteration in the in-situ profile.

Kaolinite is present in accretion-gley as a detrital mineral.

Where the accretion-gley surfaces subsequently become well drained, the resultant GB-zones show the effects of alteration in an oxidizing environment. This is in effect a second reversal of environment that resulted in the broadening of the montmorillonite diffraction peaks, the elimination of pedogenic vermiculite, and the formation of goethite.

The clay minerals of Sangamon and Yarmouth in-situ soil profiles are characterized by (1) gradual changes in composition upward from the CC-zone, (2) elimination of chlorite or vermiculite in the B-zone, (3) persistence of a significant amount of illite upward through the B-zone, (4) the formation of heterogeneous swelling material (B-clay) in the B-zone, and (5) the presence of goethite throughout the profile. The clay minerals of accretion-gley profiles are characterized by (1) a sharp clay-mineral discontinuity at the base of the accretion-gley, (2) formation of pedogenic vermiculite, (3) little or no illite detectable, (4) pedogenic formation of montmorillonite, and (5) absence of goethite.

Rocks and Minerals

The comparative stability of those rocks and minerals that are present in sufficient abundance to permit analysis of their modification in the weathered zones on the Illinoian and Kansan tills appears to be approximately as shown in table 32. This represents a generalization that could be refined with more precise analytical work and with more closely spaced bulk samples. The six sections from which the bulk samples were obtained do not necessarily represent the maximum range of variations in composition in the profiles. Although 39 categories of rocks and minerals were differentiated in the analyses, many of them combine several rock types that have significant ranges in weathering resistance.

Stable

The stable rocks and minerals are those for which there is scant, if any, evidence of depletion in the weathered zones. These minerals increase in relative abundance in proportion to the depletion of the less stable constituents, and they are not altered or significantly etched in the process. A possible exception is chert, some grains and pebbles of which are etched, but these probably were originally calcareous chert.

Table 32. – Comparative stability of the most common rocks and minerals in the weathered zones on Illinoian and Kansan till

Stable	High	Medium	Low	Unstable
Quartz	Feldspars	Garnet	Hornblende	Dolomite
Quartzite	Epidote	Hypersthene	Augite	Limestone
Chert	Opaque Heavy Minerals	Granite	Diorite	Shale
Zircon		Basalt	Sandstone	
Tourmaline			Siltstone	
Staurolite				

High Stability

These rocks and minerals are not noticeably depleted in the lower parts of the B-zones but show some depletion at the top. The feldspars fall largely within this class, but they range from stable to medium. In these profiles, the feldspars, as a group, appear to be much more resistant to decomposition than is generally accepted. The closely spaced samples previously analyzed (Frye, Willman, and Glass, 1960) show a greater loss of soda-lime feldspar relative to potash feldspar than is indicated by our bulk samples, and they probably are more representative. The feldspars in these tills are derived chiefly from pre-existing sediments and have been through previous cycles of weathering. Therefore, they represent the more resistant types, which accounts for their persistence in the B-zones. The resistance to weathering of the feldspars is shown by their common occurrence in the clay fractions of the B-zone samples.

The persistance of the feldspars through the profiles indicates that (1) no large proportion of the clay in the B-zones can be derived from decomposition of the feldspars, (2) these soils do not approach an "end point" residuum, in which all but the most stable silicates are decomposed and equilibrium with the environment is attained, and (3) the base of the B-zone does not represent the "advancing front" of a zone of complete decomposition of silicates as interpreted in the gumbotil hypothesis.

Epidote is typical of the high stability class with essentially no loss except at the top of the profile. It shows only a small depletion in the Sangamon Soil profiles but much greater loss at the top of the Yarmouth Soil.

Medium Stability

The rocks and minerals in this group show small depletion at the base of the B-zone but are greatly depleted at the top. Garnet is typical of this group. Although somewhat irregular in behavior, it is more depleted than epidote, but it is much more stable than hornblende.

The evidence concerning hypersthene is not entirely adequate, but hypersthene is clearly more stable than hornblende and other ferromagnesian minerals.

Although granite responds much the same as feldspar, its higher losses probably are caused more by disaggregation than by decomposition.

Basalt and greenstone are combined in the counts and probably include rock types with a considerable range of stability. The percentage loss in the bulk samples suggests less stability than anticipated from other evidence.

Low Stability

The rocks and minerals in this group show depletion lower in the profile than the more stable types and are greatly depleted at the tops of both the Sangamon and Yarmouth Soil profiles. Even these minerals are not entirely decomposed at the top of the profiles.

Sandstone and siltstone have a long range in stability, but many of the locally derived rocks of these types are relatively weak. Many are lost by disaggregation and are almost entirely absent at the top of some sections. Many of these pebbles are slightly calcareous and, therefore, more readily broken down, some of them in the CL-zone. A few silicified or quartzitic sandstone pebbles, not abundant enough to be differentiated, are relatively stable.

Unstable

The unstable rocks and minerals are those that at least partially disappear in the CL-zone and entirely disappear from the B-zone. The most prominent of these are limestone and dolomite. Shale and the more calcareous sandstone and siltstone pebbles are also in this class and are lost largely by disaggregation.

The differentiation of the CC- and CL-zones is based on reactivity of matrix material to dilute (about 10 percent) hydrochloric acid. Dolomite and limestone pebbles remain in the CL-zone in about half of the bulk samples. In some, the limestone pebbles are gone, only dolomite remaining. The effect of solution of the smaller pebbles is to increase the relative abundance of the larger pebbles.

In the calcareous zone, limestone or calcite commonly is entirely leached in the upper few inches and is greatly reduced in abundance to a depth of a few feet. The depth probably depends on abundance of carbonates, texture, and drainage.

Carbonates have peaks of abundance in the silt and pebble fractions, and consequently weathering increases the relative abundance of quartz sand in the in-situ profiles. Sand generally decreases in the accretion-gleys.

Accretion-gley

Whereas the clay-mineral assemblages and the grain-size distributions show a strong contrast between in-situ and accretion-gley profiles, the rock and mineral analyses show compositions that are essentially similar for the in-situ B-zones and accretion-gleys. In the accretion-gley profiles, however, a sharp change commonly occurs at the top of the till, and an erratic distribution of many of the heavy minerals suggests sorting. The similar degree of depletion of the low stability minerals, for example hornblende, in the two situations indicates that both have been subjected to comparable degrees of destructive weathering, which is consistent with the derivation of the materials of the accretion-gley deposit from the adjacent till surface but is quite inconsistent with the concept of complete silicate decomposition as was proposed for the "gumbotils."

Wisconsinan Tills

The B-zones of the soil profiles on Woodfordian drift are generally developed in loess, and therefore they do not record the effect of weathering of the till. In most of the area of Woodfordian drift, the only effect of weathering on the nonclay minerals of the tills is the solution of carbonates from a few inches at the top and oxidation to a somewhat greater depth. In areas where the Richland Loess is more than approximately 5 feet thick, the till is generally calcareous to the top. Analyses of a few samples (Frye, Willman, and Glass, 1960, table 4) of profiles on Altonian drift suggest that there is only a minor loss of hornblende and essentially no loss of the more stable rocks and minerals at the top of the B-zone and in the A-zone of the in-situ profiles. In the accretion-gleys on Altonian age tills, the degree of hornblende loess is significantly less than in the Sangamon or Yarmouth accretion-gleys. This is most apparent in areas where the loess is thin and probably accumulated so slowly that weathering was effective throughout the interval of loess accumulation.

CONCERNING THE TERM "GUMBOTIL"

We have suggested that the term "gumbotil" is not appropriate for the material that we call accretion-gley for the following reasons.

(1) The material described as gumbotil is neither till nor weathered till but is a deposit that accumulated slowly in a reducing environment.

(2) In Iowa, where the concept was developed by Kay (1916), the term gumbotil seems to have been used for all the soils on the Kansan till plain, because no other type is described. However, the examples cited as typical gumbotil, in all localities that we have examined, are accretion-gleys, and the empirical definition of gumbotil clearly applies to the accretion-gleys. In our experience, the reddish brown to dark gray-brown soils on the Kansan till plain in Illinois and eastern Iowa are in-situ profiles, and they are found in close association with the gray profiles described as gumbotil. Because Kay interpreted all the profiles as the product of weathering of the till in place, it is apparent that none of the soils were recognized as deposits on the surface of the till.

(3) The term gumbotil has not been generally used by soil scientists, partially because modern soils in the midwestern region are developed mainly on younger loess deposits. The concept as developed by Kay and associates generally has been used only by glacial geologists in Iowa, Illinois, Missouri, Kansas, and Nebraska, and the term has had little use in foreign literature.

(4) Such material commonly is called humic-gley in soil literature, indicating a soil that is gleyed, with the iron in a reduced state. Humic-gley soils contain a significant amount of organic material, which contributes to their dark to very dark gray color. Thus, the term humic-gley soil can include in-situ soils. The term accretion-gley is a genetic term used to differentiate the material formed by slow accretion in low areas from soils developed in place.

(5) The in-situ profiles range from well drained to poorly drained. They are completely gradational, and it would be difficult to set up field criteria by which the more poorly drained in-situ soils could be differentiated as a group in order to designate them as "gumbotil." In Illinois, such poorly drained in-situ profiles would not include the previous "gumbotils," but would be types previously called "mesotil."

Since we stated (Frye, Shaffer, Willman, and Ekblaw, 1960; Frye, Willman, and Glass, 1960) that the term gumbotil was not suitable for this material, opposing viewpoints have been expressed.

Trowbridge (1961) recognized that a differentiation between in-situ and depositional soils should be made, but he assumed that gumbotil as defined by Kay is an in-situ soil, which is contrary to our findings.

Leighton and MacClintock (1962) supported their original interpretations (Leighton and MacClintock, 1930). They now recognize the existence of accretion-gley but contend that such deposits are not the material they called gumbotil. Our findings are (1) if there are two similar materials, gumbotil and accretion-gley, Leighton and MacClintock (1930) did not differentiate them in their previous studies, because they did not attribute any of the soils to deposition, even though accretion-gleys are abundant and widely distributed; (2) that the one deposit Leighton and MacClintock (1962) specifically described as an example of gumbotil is accretion-gley (Effingham Section); and (3) after field experience with the advocates and supporters of the gumbotil concept, and after many years usage of the term themselves, the authors of the accretion-gley interpretation (Frye, Shaffer, Willman, and Ekblaw, 1960) can see no possibility that gumbotil, particularly as the term has been used in Illinois, is other than the accretion-gley.

Ruhe (1965; also, Ruhe and others, 1965) on the other hand, takes the position that the term gumbotil has been applied in Iowa to a variety of soil types, including depositional soils, and the term gumbotil may be applied to the accretion-gleys, even though they are not weathered till, on the justification of long usage. Our disagreement with this position, in addition to the general objections to the term we have previously given, are as follows. (1) For 25 years, gumbotil was restricted in Illinois to the one type of soil that is not derived from in-situ weathering of the till—the accretion-gleys. This usage has been followed more widely than the older and probably broader usage in Iowa. (2) As gumbotil was proposed as a genetic term, based on a specific concept of origin, gumbotil must remain identified with that concept. If future studies show that the gumbotil concept has more merit than we presently conclude, it should not be handicapped by repeated redefinition. (3) Long usage does not prevent abandonment of a genetic term when the genetic concept is found to have been in error.

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SELECTED GEOLOGIC SECTIONS

Following are the 12 measured geologic sections from which the samples were collected for this study; additional data are drawn from sections described in Circulars 295 and 347. The numbers enclosed in parentheses, for example (P-2112), are sample numbers used in the tables and illustrations in this report. The sections are arranged alphabetically by name.

BUNKER HILL SECTION

Measured in roadcut in SW¼ SW¼ NE¼ sec. 28, T. 7 N., R. 7 W., Macoupin County, Illinois (1962).

	Thickness (feet)
Pleistocene Series	
Wisconsinan Stage	
Woodfordian Substage	
Peoria Loess	
3. Loess, massive, leached, gray; contains thin discontinuous zone of brown limonite at base	2.5
2. Silt, gleyed, massive, leached, light gray; contains some clay (P-1420 top)	3.5
Wisconsinan Stage (Altonian Substage) and Sangamonian Stage	
Sangamon Soil and Roxana Silt	
1. Accretion-gley of silt and clay, massive, leached, gray; dispersed pebbles abundant in lowermost part; clay content increases and silt content decreases downward; locally incipient columnar structure (P-1418 base; P-1419 top)	4.5
Total	10.5

CHAPIN SECTION

Measured in roadcut in NW¼ SE¼ NE¼ sec. 8, T. 15 N., R. 11 W., Morgan County, Illinois (1965). This section is described in detail in supplement to INQUA Guidebook for trip C, 1965, and reissued as Illinois State Geological Survey reprint and is given here only in skeleton form.

	Thickness (feet)
Pleistocene Series	
Wisconsinan Stage	
Woodfordian Substage	
Peoria Loess	
10. Loess, leached, massive; surface soil in top (P-2129 top of B-zone; P-2128 lower B-zone, 4 ft. below surface; P-2127, 4 ft. above base; P-2126, 2 ft. above base; P-2125 base)	10.0
9. Loess, calcareous, massive, tan and gray mottled (P-2124 top; P-2123 base)	1.0
8. Loess, very weakly calcareous (P-2122)	0.5
Altonian Substage	
Roxana Silt (Zones II-IV)	
7. Loess, coarse, massive, leached, pinkish brown (P-2121 top; P-2120, 4 ft. above base; P-2119, 3 ft. above base; P-2118, 2 ft. above base; P-2117, 1 ft. above base)	5.5
Roxana Silt (Zone Ib)	
6. Silt and fine sand, leached, massive (P-2116 top; P-2115, ½ ft. below top; P-2114 base)	1.5
Roxana Silt (Zone Ia)	
5. Silt and sand with small pebbles, leached, massive (P-2113, ½ ft. below top; P-2112 base)	1.5
Illinoian Stage	
Liman Substage	
Sangamon Soil	
4. Sangamon Soil developed in till; B_1 or A-zone top ½ ft. (P-2111); B_2-zone ½–2½ ft. below top (P-2110 top; P-2109 middle; P-2108 base); B_3-zone 2½–4 ft. below top (P-2107 middle); CL-zone 4–6½ ft. below top (P-2106 upper; P-2105 middle; P-2104 base)	6.5
3. CC-zone of Sangamon Soil developed in till, calcareous, tan-brown; top 1 ft. dolomite zone (P-2103); lower 4 ft. strongly calcareous (P-2102 top; P-2101 base)	5.0
2. Till, calcareous, gray to blue-gray, partly covered in lowermost 10 feet (P-2100 top; P-2099, 11 ft. below top)	33.0
Pennsylvanian System	
1. Shale, poorly exposed to level of creek	15.0
Total	79.5

DONNELLSON SECTION

Measured in overburden in face of active quarry 4 miles north of Donnellson in NE¼ NE¼ NW¼ sec. 10, T. 68 N., R. 6 W., Lee County, Iowa (1962).

	Thickness (feet)
Pleistocene Series	
Wisconsinan Stage	
Woodfordian Substage	
Peoria Loess	
8. Loess, massive, leached, tan-brown; deeply developed surface soil in top (P-1313 near base)	5.0
Altonian Substage	
Roxana Silt	
7. Loess, pebbly, leached, brown, massive (P-1312)	1.0

	Thickness (feet)
Sangamonian, Illinoian, and Yarmouthian Stages	
Yarmouth and Sangamon Soil	
6. A-zone of silt, clay and sand, contains few small pebbles, massive, leached, tan-brown	0.5
5. GB-zone of clay, silt, and sand with small pebbles dispersed throughout, micro-blocky, leached, mottled gray and brown; the material in which this secondary B-zone is developed appears to have been accretion-gley of the Yarmouth Soil. At one side of quarry a thin lens of Sangamon accretion-gley occurs at a somewhat lower level on the soil surface. (P-1311 top; P-1310 middle; P-1309 base;P-1301 middle 1 ft.)	2.0
Kansan Stage	
Yarmouth Soil	
4. B-zone of Yarmouth Soil developed in till, clay, silt, sand, and pebbles; distinctly more pebbly and cobbly than GB-zone above; leached, massive, red-brown with gray-tan mottled with gray in lower part, streaks and splotches of Mn-Fe staining strongly developed in lower half; contains clay skins, and some krotovinas with gray fillings; gradational at base (P-1308 from 1 ft. below top; P-1307 base; P-1300 middle 1½ ft.)	2.5
3. CL-zone and B_3-zone of Yarmouth Soil developed in till, leached, tan, jointed; the B_3-zone appears to be 3–4 inches of transition at the top of unit (P-1306 from 1 ft. below top; P-1305 from 1 ft. above base; P-1299 from middle 2 ft.)	6.0
2. Till, calcareous, massive to blocky and jointed, tan; in upper 1–3 ft. is C_{ca}-zone of soil profile with strongly developed nodules and stringers of caliche up to more than 1 inch across; bottom 10 ft. contains oxidized, calcareous sand and sand and gravel interbedded with tan calcareous till (P-1304 from 1 ft. below top; P-1303 from 7 ft. below top; P-1302 from 12 ft. below top; P-1298 from 5–6 ft. below top)	27.0
Pennsylvanian System and Mississippian System	
1. Shales and clays of Pennsylvanian age, gray and black with coaly streaks; irregular contacts at top and bottom; overlies limestone of Mississippian age	
Total Pleistocene	44.0

EFFINGHAM SECTION

Measured in side of drainage ditch excavation in SE cor. NW¼ sec. 6, T. 7 N., R. 6 E., Effingham County, Illinois (1962).

	Thickness (feet)
Pleistocene Series	
Wisconsinan Stage	
Peoria Loess and Roxana Silt	
5. Silt with some sand, small pebbles sparsely dispersed in lower part, noncalcareous, massive, yellow-tan to light tan; contains surface soil in top	3.5
Sangamonian Stage	
Sangamon Soil	
4. Accretion-gley of sand, silt, and clay, noncalcareous, massive; contains a few small pebbles dispersed throughout; sharp contact at top and gradational at base; krotovinas of overlying loess occur in upper part and produce a mottling of light tan in a dark gray to black matrix (P-1279 lower part)	3.5
3. Accretion-gley of sand, silt, and clay, noncalcareous, massive, mottled; thin lenses and zones of organic material occur throughout; krotovinas up to more than 1 inch in diameter distributed throughout; the fillings of krotovinas resemble the material that occurs 1 to 3 ft. above their position; lower part 60% tan-brown and 40% medium gray grading upward to 5% tan-brown, 50% medium gray, and 45% dark gray at top; small pebbles occur sparsely throughout and a few cobbles in lowermost part; contact at top gradational but sharp at base (P-1278 upper half; P-1277 lower half)	3.5
Illinoian Stage	
2. Till, laminated, calcareous in lower half, weakly calcareous to leached in upper half, gray in lower part with brown on joint surfaces becoming brown progressively upward; cobbles with maximum diameter of 4 inches sparsely dispersed throughout; upper part contains lenses and discontinuous thin zones of sand; near the top (locally at the top) is a zone of darker brown limonite 1 to 3 inches thick (P-1276-A); locally gray clayey sand occurs at the top (P-1276-B); thickness of unit ranges from 3½ to 4 ft. above the sharp horizontal contact at base (P-1275 middle of lower half; P-1276 middle of upper half)	4.0

	Thickness (feet)
1. Till, massive, tough, blocky, calcareous, gray to dark gray; contains cobbles up to 6 inches in diameter; top is sharply defined by pavement of oriented and striated cobbles; a few sand dikes are truncated by the till above the cobble pavement; a few pieces of wood occur in the till (P-1274 from $3\frac{1}{2}$ ft. below top)	7.0
Total	21.5

FAIRVIEW (IN-SITU) SECTION

Measured in roadcuts in SE$\frac{1}{4}$ NE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 36, T. 8 N., R. 2 E., Fulton County, Illinois. This section has been published (Frye, Willman, and Glass, 1960) and is given here only in skeleton form.

Pleistocene Series	
Wisconsinan Stage	
Woodfordian Substage	
Peoria Loess	
6. Loess, leached, tan, massive; surface soil in top	10.0
Altonian Substage	
Roxana Silt	
5. Silt with some clay and sand, leached, tan-brown	1.0
Illinoian Stage	
Sangamon Soil	
4. A-zone of Sangamon Soil in till	1.2
3. B-zone of Sangamon Soil in till (P-1316 middle part)	3.5
2. CL-zone of Sangamon Soil in till (P-1315 middle part)	3.0
1. Calcareous till; CC-zone of soil (P-1314 middle part)	4.0+
Total	22.7

FORT MADISON SECTION

Measured in roadcuts south of "Rodeo Park," N of Fort Madison, Iowa, NW$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 33, T. 68 N., R. 4 W., Lee County, Iowa (1962).

	Thickness (feet)
Pleistocene Series	
Wisconsinan Stage	
Woodfordian Substage	
Peoria Loess	
8. Loess, massive, leached, friable, tan; surface soil in top	10.0
Illinoian Stage	
7. Sangamon Soil developed in till; B-zone brown, massive to blocky, containing clay skins and a few Mn-Fe pellets; A-zone not present; lowermost 1 ft. weakly calcareous (P-1297 middle; P-1296 base)	5.0
Yarmouthian Stage	
Yarmouth Soil	
6. Accretion-gley, oxidized, noncalcareous, massive, mottled brown and gray with nodes of dark brown clay (P-1295)	1.5
5. Accretion-gley; massive to microblocky, gray with some mottling of tan and brown, very plastic; at top gradational with oxidized accretion-gley above but sharp contact at base (P-1291 from 2–3 ft. below top; P-1290 from 1–3 ft. above base)	11.5
Kansan Stage	
4. Yarmouth Soil, CL-zone developed in till; leached, tan-brown, gradational at base but sharp contact at top (P-1289 middle part)	4.0
3. Till (partly covered), calcareous, compact, massive, gray in lower part but tan near top; caliche nodules from Yarmouth Soil dispersed in uppermost part (P-1288 from 48 ft. above base; P-1294 lower part)	62.0
Nebraskan Stage and Aftonian Stage	
2. Silt, clay, and sand (accretion-gley) contorted with lenses of till and iron-cemented sand and gravel (partly covered), light tan, brown, and dark gray, locally weakly calcareous and contains small caliche nodules; at other places noncalcareous. Although the relations are not clear it appears to be an Afton Soil accretion-gley contorted by overriding Kansan glacier (P-1293)	4.0
Nebraskan Stage	
1. Till, calcareous, compact, blue-gray, strongly jointed with 1 inch oxidized rinds along the joint planes; to bottom of creek (P-1292; P-1292-A similar till from $\frac{1}{4}$ mile west along creek valley)	2.0
Total	100.0

FUNKHOUSER SECTION

Measured in gully south of highway U.S. 40 and west of Cemetery in SE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 4, T. 7 N., R. 5 E., Effingham County, Illinois, on highest point in local topography (1962).

Pleistocene Series	
Wisconsinan Stage	
Woodfordian Substage	
Peoria Loess	
9. Loess, tan-brown, leached, massive, surface soil in top	3.5

	Thickness (feet)
Altonian Substage	
Roxana Silt	
8. Silt, with some sand and a few small pebbles in lower part, leached, light brown; indistinctly developed podzolic soil in top	2.5
Illinoian Stage	
Sangamon Soil	
7. B-zone of Sangamon Soil developed in till, leached, micro-blocky, red-brown; Mn-Fe pellets and splotches and clay skins well developed (P-1287 from ½ to 2 ft. below top; P-1324 from 2 to 3½ ft. below top)	3.5
6. CL-zone of Sangamon Soil in till, leached, oxidized, tan to reddish brown; some Mn-Fe pellets in upper part, platy structure of till indistinctly preserved in lower part (P-1323 from top to 1½ ft. below top)	2.0
5. C_{ca}-zone of Sangamon Soil in till, calcareous, oxidized, light brown to gray; contains nodules and stringers of caliche throughout; platy structure of till distinct (P-1286 bottom half)	2.0
4. Till, calcareous, platy structure, gray-brown; lacks visible evidence of soil development (P-1322 middle 1½ ft.)	3.0
3. Sand and gravel, calcareous, tan; small abandoned gravel pit	8.0
2. Till, calcareous, massive, blue-gray; contains large boulders in lower part (probably equivalent to massive till below striated pavement at nearby Effingham Section) (P-1321 lower)	15.0
1. Sand and gravel with some small boulders, calcareous, irregular iron cemented zones, cross-bedded; to bottom of gulley	10.0
Total	49.5

FUNKHOUSER EAST SECTION

Measured in roadcuts of U.S. highway 40 in SE¼ SW¼ SW¼ sec. 34, T. 8 N., R. 5 E., Effingham County, Illinois (1962).

	Thickness (feet)
Pleistocene Series	
Wisconsinan Stage	
Peoria and Roxana Loesses	
4. Loess, massive, leached, tan-brown, lowermost part sandy with a few small pebbles and darker brown	5.0
Sangamonian Stage	
Sangamon Soil	
3. Accretion-gley of clay and silt with some sand, massive, non-calcareous, light gray at base becoming darker gray upward; contains pebbles in lower part (P-1283 top; P-1282 bottom)	4.0
Illinoian Stage	
2. Till, leached, friable, tan-brown, platy (C-zone of Sangamon Soil); contains krotovinas in upper part (P-1281 middle)	2.5
1. Till, calcareous, tan-brown to gray in upper part and gray in lower part; upper half has platy structure; lower half massive with sharp contact at top (P-1280 upper; P-1284 lower)	12.0
Total	23.5

HIPPLE SCHOOL (ACCRETION-GLEY) SECTION

Measured in roadcut in NW¼ SW¼ SW¼ sec. 8, T. 7 N., R. 3 E., Fulton County, Illinois. This section has been published in detail and is given here only in skeleton form (Frye, Willman, and Glass, 1960; Frye and Willman, 1963).

	Thickness (feet)
Pleistocene Series	
Wisconsinan Stage	
Woodfordian Substage	
Peoria Loess	
7. Loess, leached, massive, light-brown (P-1459 lower; P-1460 middle)	5.0
Altonian Substage	
Roxana Silt	
6. Loess, leached, massive, pinkish tan-brown (P-1456–8)	2.0
5. Silt, clay, and sand, leached, brown (P-1455)	0.5
Sangamonian Stage	
Sangamon Soil	
4. Accretion-gley, noncalcareous, micro-blocky (P-785 from 1 ft. above base; P-786–9 distributed evenly to top; P-1320 from middle of upper half, including P-787–8; P-1319 from lower half including the basal contact and zone of pebble concentrate at base, including P-784, P-785, and zone between)	5.5
Illinoian Stage	
3. BG-zone of Sangamon Soil in till (P-784 at top contact; P-783 lower)	0.8

	Thickness (feet)
2. CL-zone of Sangamon Soil in till (P-782 upper; P-781 lower; P-1318 upper half including P-782)	2.5
1. Till, calcareous; CC-zone of Sangamon Soil at top; some sand zones in lower part (P-780 top; P-779 from 1 ft. below top; P-1317 from 10 ft. below top)	12.0+
Total	28.3

LONE OAK SECTION

Measured in roadcut in NW$\frac{1}{4}$ SW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 29, T. 3 S., R. 5 W., Adams County, Illinois (1964).

Pleistocene Series	
Wisconsinan Stage	
Peoria and Roxana Loesses	
6. Loess, massive, leached, tan-brown	3.0
Kansan Stage	
"A-zone" of Sangamon Soil	
5. Pebbles and small cobbles of chert with a few pebbles of metamorphic and igneous rocks; a lag gravel derived from Kansan till and colluvially veneered on surface of underlying shale; as the soil below was developed through the gravel, it occupies position of an A-zone	0.2
Pennsylvanian System – shale of the Abbott Formation	
Sangamon Soil	
4. B_2-zone of Sangamon Soil developed in shale; massive, leached, clayey, dark red to red-brown; contains Mn-Fe pellets and "splotches" up to $\frac{1}{2}$-inch across; sharp contact at top, gradational at base (P-1847—P-1843 distributed evenly from top to bottom; P-1738 = P-1845 in position)	2.5
3. B_3-zone of Sangamon Soil in shale, massive to indistinctly preserved shale bedding, leached, red-brown with mottling of yellow-tan and pink; contains sparse small pellets of Mn-Fe; gradational top and bottom (P-1737 and P-1842 middle)	0.5
2. C_1-zone of Sangamon Soil in shale; shale bedding indistinct to distinct, yellow-tan with pink mottling; gradational contacts (P-1841 middle)	0.5

	Thickness (feet)
1. C-zone and parent material of Sangamon Soil; shale, well bedded, grayish yellow-tan at top grading downward to dark gray-green (P-1736, 0.7 ft. below top; P-1840, 3 ft. below top)	4.0
Total	10.7

MERIDIAN ROAD NO. 1 SECTION

Measured in roadcut in NW$\frac{1}{4}$ NW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 7, T. 43 N., R. 1 E., Winnebago County, Illinois (1959).

Pleistocene Series	
Wisconsinan Stage	
Woodfordian Substage	
Peoria Loess	
4. Loess, massive, leached, gray-tan; the loess has been truncated so that all that is present in this section is in the A-zone of underlying soil profile	1.5
Altonian Substage	
Winnebago Till and outwash	
3. B-zone of late Wisconsinan soil developed in coarse, permeable till or glacial outwash; gravel, noncalcareous, massive, clayey, red-brown, contains some sand (P-704 top; P-703 middle; P-702 bottom)	2.5
2. B_3-zone and upper part of C-zone developed in till; till, sandy with some pebbles and clay, massive, leached, tan-brown (P-701 top; P-700 middle; P-699 bottom)	2.0
1. Till, massive, sandy, calcareous, tan to pale pinkish tan; contains a few small nodules of secondary $CaCO_3$ and cobbles up to $\frac{1}{2}$-foot in diameter (P-698 upper part)	5.0
Total	11.0

PANAMA-A SECTION

Measured in roadcut in SW$\frac{1}{4}$ SW$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 23, T. 7 N., R. 4 W., Montgomery County, Illinois (1962).

Pleistocene Series	
Wisconsinan Stage	
Woodfordian Substage	
Peoria Loess	
8. Loess, massive, leached, tan grading to gray-tan at base with some gray and tan mottling in lower part (P-1404); well developed surface soil is not present	2.0

	Thickness (feet)
Farmdalian Substage	
Farmdale Silt	
7. Silt, sand, and clay, with well defined humus zone at top, massive to indistinct zonation, leached; sharp contacts at top and bottom (P-1403 from upper part)	1.0
Altonian Substage	
Roxana Silt	
6. Sand and silt with some clay, gleyed, lead gray to dark gray; humus zone at top gradational downward (P-1402 top; P-1401 bottom)	2.0
Sangamonian Stage and Illinoian Stage	
Sangamon Soil	
5. Accretion-gley of silt, clay and some sand, massive, leached, light gray; locally contains streaks of sand; contains krotovinas that resemble the humus in the unit above (P-1400 top; P-1398 middle; P-1399 sample of krotovinas)	4.0
4. Accretion-gley of sand, silt and clay, massive, leached, mottled tan-brown and gray (P-1397 top)	2.0
3. Sand and silt, irregularly cemented with limonite, dolomitic, tough, brown, variable in thickness (P-1396)	0.5
2. Accretion-gley of sand, silt and clay, with a few dispersed pebbles more abundant in lower part, mottled tan-brown and gray, leached, loose (P-1395 lower)	2.0
Illinoian Stage	
Liman Substage	
1. Till, calcareous, massive, dense, tan and gray with some mottling (P-1394 near bottom)	2.0
Total	15.5

TABLE 1 – GRAIN SIZE ANALYSES OF BULK SAMPLES

Sample no.	Zone	Fractions in mm (percent by weight)																					
		38	16	8	4	2	Pebbles	1	.5	.25	.125	.062	Sand	.03	.016	.008	.004	Silt	.002	.001	.0005	<.0005	Clay
Donnellson																							
P-1301	GB	-	0.2	0.2	0.4	0.6	1	1	2	5	5	3	16	10	9	7	5	31	5	7	11	29	52
1300	B	-	0.1	0.4	0.7	1	3	2	5	11	12	10	40	15	8	5	5	33	3	3	3	15	24
1299	CL	-	0.1	0.5	0.9	1	3	11	13	14	6	2	46	13	8	5	4	30	3	3	3	12	21
1298	CC	-	0.5	0.9	1	2	5	2	6	13	11	8	40	14	8	6	5	33	4	2	3	13	22
Effingham																							
P-1279	G	-	-	0.1	0.2	0.3	1	0.4	2	8	17	8	35	15	13	8	5	41	3	2	3	15	23
1278	G	-	-	0.3	0.3	0.4	1	1	3	19	19	9	51	12	9	5	4	30	2	2	2	12	18
1277	G	-	0.6	0.6	0.6	0.7	3	1	4	16	20	11	52	12	8	5	3	28	2	2	2	11	17
1276	CC	-	0.7	1	2	2	6	4	8	17	12	9	50	10	9	7	6	32	3	2	2	5	12
1275	U	*	0.7	2	3	4	9	4	6	10	10	8	38	12	9	10	4	35	6	3	2	7	18
1274	U	-	0.6	1	3	3	8	4	6	12	10	8	40	12	9	8	6	35	4	4	3	6	17
Fairview																							
P-1316	B	-	0.5	0.8	0.9	1	4	1	2	6	5	5	19	15	12	10	4	41	12	6	5	13	36
1315	CL	-	0.5	1	1	1	4	1	3	7	6	7	24	14	9	11	10	44	7	5	5	11	28
1314	CC	*	7	4	4	4	18	3	4	8	8	8	31	12	9	8	7	36	4	2	3	6	15
Fort Madison																							
P-1291	G	-	-	-	0.1	0.1	+	1	2	4	4	3	14	12	12	12	7	43	4	2	5	32	43
1290	G	-	0.1	+	0.2	0.3	1	1	5	10	9	8	33	16	10	7	5	38	2	3	5	18	28
1289	CL	-	0.4	0.9	1	1	4	2	8	15	12	10	47	14	7	6	5	32	3	2	3	9	17
1288	CC	-	0.2	0.8	1	2	4	3	8	13	12	10	46	14	8	5	4	31	4	2	3	10	19
Funkhouser																							
P-1287	B	*	0.8	1	2	2	6	2	6	11	10	6	35	12	8	7	6	33	4	3	3	16	26
1324	B	*	0.6	0.9	2	2	6	2	4	16	12	7	41	14	9	7	5	35	3	2	3	10	18
1323	CL	-	0.9	1	2	2	6	2	4	15	11	9	41	13	11	7	6	37	5	2	2	7	16
1286	CC	-	0.7	2	3	4	10	4	6	8	10	8	36	13	11	8	6	38	4	3	2	7	16
1322	CC	*	0.3	2	3	4	10	4	4	14	8	8	38	13	9	8	6	36	4	2	3	7	16
Hipple																							
P-1320	G	-	0.4	0.4	1	1	3	1	2	7	6	4	20	15	12	10	7	44	4	5	7	17	33
1319	G	*	3	4	4	3	14	3	5	9	6	4	27	14	9	8	6	37	3	3	3	13	22
1318	CL	-	0.6	1	2	1	5	2	3	8	6	5	24	12	10	11	8	41	7	5	4	14	30
1317	U	*	3	3	3	3	11	2	5	9	5	5	26	14	7	10	8	39	5	4	4	11	24

* Present but not representative and excluded.
\+ Less than 0.5 percent.

TABLE 2 — X-RAY DIFFRACTION ANALYSES OF LESS THAN 2-MICRON FRACTION.

Sample no.	Counts per second: Calcite	Counts per second: Dolomite	D. I. ratio	Percent of clay mineral: Montmorillonite	Percent of clay mineral: Illite	Percent of clay mineral: Kaolinite and Chlorite	Orders of Chlorite basal reflections: 001	Orders of Chlorite basal reflections: 003	Orders of Chlorite basal reflections: 004	Kaolinite	Goethite and Lepidocrocite	Bed no. in measured section	Zone in profile
BUNKER HILL													
P-1420	-	-	1.8	74	19	7	-	-	-	+		2	G
1419	-	-	0.5	86	5	9	-	-	-	+		1	G
1418	-	-	0.5	84	7	9	+	+	-	+		1	G
CHAPIN													
P-2129	-	-	1.6	50**	35	15	-	-	-	+	G	10	B
2128	-	-	2.1	57**	32	11	-	-	-	+	G	10	B
2127	-	-	1.6	59**	29	12	-	-	-	+		10	CL
2126	-	-	1.3	69	21	10	-	+	-	+		10	CL
2125	-	-	1.4	71	20	9	+	+	-	+		10	CL
2124	-	275	1.4	70	20	10	+	+	-	+		9	CC
2123	-	115	1.4	68	22	10	+	+	-	+		9	CC
2122	-	?	0.5	72	11	17	+	+	+	+	G	8	
2121	-	-	0.6	77	10	13	+	-	-	+		7	CL
2120	-	-	0.3	73	9	18	+	+	-	+		7	CL
2119	-	-	0.5	72	11	17	+	-	-	+		7	CL
2118	-	-	0.5	72	11	17	-	-	-	+		7	CL
2117	-	-	0.5	70	13	17	-	-	-	+		7	CL
2116	-	-	0.7	60	20	20	-	-	-	+		6	CL
2115	-	-	0.5	59	18	23	-	+	-	+		6	CL
2114	-	-	0.6	59	20	21	-	+	-	+		6	CL
2113	-	-	0.5	55**	19	26	-	-	-	+		5	A
2112	-	-	0.6	54**	21	25	-	-	-	+		5	A
2111	-	-	0.8		†		-	-	-	+	G	4	B
2110	-	-	0.9		†		-	-	-	+	G	4	B
2109	-	-	0.9		†		-	-	-	+	G	4	B
2108	-	-	0.9	52	27	21	+	+	-	+	G	4	B
2107	-	-	1.0	55	26	19	+	+	-	+	G	4	B
2106	-	-	1.2	49	33	18	+	+	-	+	G	4	CL
2104	-	-	1.7	52	34	14	+	+	-	+	G	4	CL
2103	-	30	1.7	52	34	14	+	+	-	+	G	3	CC
2102	6	80	2.6	44	44	12	+	+	-	+	G	3	CC
2100	23	155	1.7	41	41	18	+	+	+	+		2	U
2099	13	47	1.1	42	38	20	+	+	+	+		2	U
DONNELLSON													
P-1313	-	8	0.4	73	9	18	-	+	-	+	G	8	CC
1312	-	-	0.3	70	9	21	-	+	-	+	G	7	CL
1311	-	-	-	71**	-	29	-	-	-	+	G	5	GB
(B)1301	-	-	-	80	-	20	-	-	-	+	G	5	GB
1310	-	-	-	73	-	27	-	-	-	+	G	5	GB
1309	-	-	-	78	-	22	-	-	-	+	G	5	GB
1308	-	-	0.2	73	6	21	-	-	-	+	G	4	B
(B)1300	-	-	0.2	77	6	17	-	-	-	+	G	4	B
1307	-	-	0.2	68	8	24	-	-	-	+	G	4	B
1306	-	-	0.3	64	10	26	-	-	-	+	G	3	CL
(B)1299	-	-	0.4	63	14	23	-	-	-	+	G	3	CL
1305	-	-	0.4	57	15	28	-	-	-	+	G	3	CL
1304	10	7	0.4	59	15	26	-	-	-	+	G	2	CC

TABLE 2 — CONTINUED

Sample no.	Counts per second		D. I. ratio	Percent of clay mineral			Orders of Chlorite basal reflections			Kaolinite	Geothite and Lepidocrocite	Bed no. in measured section	Zone in profile
	Calcite	Dolomite		Montmorillonite	Illite	Kaolinite and Chlorite	001	003	004				
DONNELLSON, continued													
(B)1298	28	16	0.5	63	15	22	-	-	-	+	G	2	CC
1303	35	18	0.4	60	14	26	-	-	-	+	G	2	CC
1302	30	15	0.4	62	15	23	-	-	-	+	G	2	CC
EFFINGHAM													
(B)1279	-	-	0.4	68**	11	21	+	+	-	+		4	G
(B)1278	-	-	0.3	80	6	14	+	+	-	+		3	G
(B)1277	-	-	0.7	70	15	15	+	+	-	+		3	G
1276B	-	-	3.6	15	72	13	+	-	-	+	G	2	CL
1276A	-	100	2.2	13	69	18	+	-	-	+	G	2	CC
(B)1276	-	80	2.7	15	68	17	+	-	-	+	G	2	CC
(B)1275	17	95	4.0	14	74	12	+	+	+	+	G	2	U
(B)1274	23	150	1.8	19	59	22	+	+	+	+		1	U
FAIRVIEW													
(B)1316	-	-	0.6	63	17	20	-	-	-	+	G	3	B
(B)1315	-	-	1.7	15	61	24	+	-	-	+	G	2	CL
(B)1314	15	40	1.6	8	65	27	+	+	+	+	G	1	CC
682	-	-	0.4	49	18	33	+	-	-	+			A
681	-	-	0.4	50	20	30	+	+	-	+	G		A
680	-	-	0.5	44	25	31	+	+	-	+	G		B
679	-	-	0.5	44	25	31	+	-	-	+	G		B
678	-	-	0.7	35	33	32	+	-	-	+	G		B
677	-	-	1.1	17	52	31	+	-	-	+	G		B
676	-	-	2.7	8	73	19	+	+	-	+	G		CL
675	-	-	2.0	6	70	24	+	+	-	+	G		CL
674A	18	25	1.6	4	68	28	+	+	+	+	G		CC
FORT MADISON													
P-1297	-	-	0.4	73	10	17	-	-	-	+	G	7	CL
1296	-	-	0.4	77	8	15	-	-	-	+	G	7	CL
1295	-	-	0.5	78**	9	13	-	-	-	+	G	6	GB
(B)1291	-	-	0.5	85	6	9	-	-	-	+		5	G
(B)1290	-	-	0.3	91	3	6	-	-	-	+		5	G
(B)1289	-	-	0.4	66	12	22	-	-	-	+	G	4	CL
(B)1288	55	20	0.3	61	13	26	-	-	-	+	G	3	CC
1294	160	45	0.4	66	13	21	-	-	-	+	G	3	CC
1293	-	-	0.3	80	6	14	-	-	-	+		2	G
1292	50	125	0.5	61	16	23	-	-	-	+		1	CC
1292A	40	50	0.5	46	22	32	-	-	-	+		1	CC
FUNKHOUSER													
(B)1287	-	-	0.9	62	22	16	-	-	-	+	G	7	B
(B)1324	-	-	1.2	57	28	15	-	-	-	+	G	7	B
(B)1323	-	-	2.3	50	39	11	-	+	-	+	G	6	CL
(B)1286	45	230	3.2	31	57	12	+	+	+	+	G	5	CC
(B)1322	40	85	2.1	19	61	20	+	+	+	+	G	4	CC
1321	15	80	1.6	12	62	26	+	+	+	+		2	U

TABLE 2 — CONTINUED

Sample no.	Counts per second		D. I. ratio	Percent of clay mineral			Orders of Chlorite basal reflections			Kaolinite	Goethite and Lepidocrocite	Bed no. in measured section	Zone in profile
	Calcite	Dolomite		Montmorillonite	Illite	Kaolinite and Chlorite	001	003	004				
FUNKHOUSER EAST													
P-1283	-	-	-	93	-	7	+	+	-	+		3	G
1282	-	-	-	92	-	8	+	+	-	+		3	G
1281	-	-	1.7	54	33	13	+	-	-	+	G	2	CL
1280	21	100	3.0	32	56	12	+	+	+	+	G	1	CC
1284	26	95	1.6	17	59	24	+	+	+	+		1	U
HIPPLE SCHOOL													
P-1460	-	-	1.5	71	20	9	-	+	-	+		7	CL
1459	-	8	0.9	84	9	7	-	-	-	+		7	CC
1458	-	-	0.5	70	13	17	+	-	-	+		6	CL
1457	-	-	0.4	73	11	16	+	-	-	+		6	CL
1456	-	-	0.2	72	8	20	+	-	-	+		6	CL
1455	-	-	0.6	68	15	17	-	-	-	+		5	A
789	-	-	0.5		†		-	-	-	+	G	4	GB
788	-	-	0.4	76	9	15	-	-	-	+		4	G
(B)1320	-	-	0.5	77	9	14	-	-	-	+		4	G
787	-	-	0.4	76	9	15	-	+	-	+		4	G
786	-	-	0.5	76	11	13	-	+	-	+		4	G
785	-	-	0.6	76	11	13	-	+	-	+		4	G
(B)1319	-	-	0.9	62	22	16	-	-	-	+	G	4	G
784	-	-	1.3	57	28	15	-	-	-	+	G	3	BG
783	-	-	1.6	50	35	15	-	-	-	+	G	3	BG
(B)1318	-	-	2.4	10	71	19	+	+	-	+	G	2	CL
782	-	-	2.7	5	76	19	+	+	-	+	G	2	CL
781	-	-	2.8	19	65	16	+	+	-	+	G	2	CL
780	10	65	3.2	8	76	16	+	+	-	+	G	1	CC
779	21	100	3.3	-	83	17	+	+	+	+	G	1	CC
(B)1317	24	75	1.9	-	74	26	+	+	+	+		1	U
LONE OAK													
P-1847	-	-	0.6	42	27	31	-	+	-	+	L,G	4	B_2
1846	-	-	0.5	41	26	33	-	+	-	+	L,G	4	B_2
1845	-	-	0.6	40	26	34	+	+	-	+	L,G	4	B_2
1738	-	-	0.5	45	24	31	+	+	-	+	L	4	B_2
1844	-	-	0.6	43	26	31	+	+	-	+	L	4	B_2
1843	-	-	0.7	43	28	29	+	+	-	+	L	4	B_2
1737	-	-	0.8	45	30	25	+	+	-	+	L,G	3	B_3
1842	-	-	0.8	45	30	25	+	+	-	+	L	3	B_3
1841	-	-	1.4	34	45	21	+	+	-	+	L,G	2	C
1736	-	-	2.2	22	60	18	+	+	+	+		1	C
1840	-	-	2.4	17	64	19	+	+	+	+		1	C
MERIDIAN ROAD													
P- 704	-	-	0.6	58	19	23	+	-	-	+	G	3	B_2
703	-	-	1.2	55	29	16	+	-	-	+	G	3	B_2
702	-	-	1.9	50	37	13	+	-	-	+		3	B_2
701	-	-	4.0	31	59	10	+	-	-	+		2	B_3
700	-	-	4.9	28	63	9	+	+	-	?		2	B_3

TABLE 2 — CONTINUED

Sample no.	Counts per second: Calcite	Counts per second: Dolomite	D. I. ratio	Percent of clay mineral: Montmorillionite	Percent of clay mineral: Illite	Percent of clay mineral: Kaolinite and Chlorite	Orders of Chlorite basal reflections: 001	Orders of Chlorite basal reflections: 003	Orders of Chlorite basal reflections: 004	Kaolinite	Goethite and Lepidocrocite	Bed no. in measured section	Zone in profile
MEDIDIAN ROAD, continued													
P- 699	-	-	8.0	26	68	6	+	+	+	-		2	B_3
698	-	40	4.6	22	68	10	+	+	+	-		1	CC
PANAMA A													
1404	-	-	0.8	71	16	13	+	+	-	+	G	8	CL
1403	-	-	0.8	89**	6	5	-	-	-	+		7	CL
1402	-	-	0.7	91	5	4	-	-	-	+		6	CL
1401	-	-	0.9	91	5	4	-	+	-	+		6	CL
1400	-	-	0.8	90	6	4	-	+	-	+		5	G
1399	-	-	0.6	90	5	5	-	+	-	+		5	G
1398	-	-	1.3	90	7	3	-	-	-	+		5	G
1397	-	-	1.4	79	14	7	-	-	-	+	L	4	G
1396	-	110	3.0	19	66	15	+	+	+	+	G	3	CC
1395	-	-	0.9	89	6	5	-	-	-	+		2	G
1394	25	95	3.9	28	62	10	+	+	+	+		1	CC

† Heterogeneous swelling material. Calculation impractical.

** Broadened diffraction peak. Weathered montmorillonite.

(B) Samples for which other mineral and rock analyses are given in tables 1, 3, and 4.

TABLE 3 — ROCKS AND MINERALS IN PEBBLE FRACTIONS (PERCENT BY NUMBER)

Sample no.	Zone	Fraction mm	Fraction % by wt.	Limestone	Dolomite	Sandstone, Siltstone	Shale gray, green	Shale black	Chert	Granite, Syenite	Diorite, Peridotite	Felsite	Basalt, Greenstone	Quartzite	Schist, Gneiss	Quartz	Feldspar	Hornblende, Augite	Others
Donnellson																			
P-1301	B	16	0.2											*					
		8	0.2			*			*				*			*			
		4	0.4			8			34	4	4		+	3		39	1		7
		2	0.6			2			15	3	1		+			68	8	+	3
1300	B	16	0.1							*									
		8	0.4			12			24	36	4		12	4		8			
		4	0.7			14			26	18	5	5	4	1		20	4		3
		2	1			4	1		12	17	1	2	3			36	24		
1299	CL	16	0.1							*									
		8	0.5			2			10	22	10	5	44	3	2	2			
		4	0.9			9	1		15	15	7	3	24	2		14	10		
		2	1			1			5	8	3	1	21			31	30		
1298	CC	16	0.5			*				*									
		8	0.9	19		13			16	13	11	4	22	1		1			
		4	1	17		12			16	18	4	1	13	1		13	4		1
		2	2	11	3	2			5	14	3	+	11			27	24		
Effingham																			
P-1279	G	8	0.1											*		*			
		4	0.2						77	1			2	1		8	11		
		2	0.3						69	+				+		11	20		
1278	G	8	0.3						89	7				2	2				
		4	0.3						68	4	1		2	2	1	17	5		
		2	0.4						68	1			2			16	13		
1277	G	16	0.6							*	*		*			*			
		8	0.6			13			66	2	5	1	3	4	1	5			
		4	0.6			9			66	2	3		3			15	1		1
		2	0.7			9			73	1	1		1			11	4		
1276	CC	16	0.7		*	*			*										
		8	1	3	23	8			37	5	4	1	11	2	1	5			
		4	2	6	24	19			33	4	2	2	4			5	1		
		2	2	4	11	18		3	28	6	2	1	6			16	4	1	
1275	CC	38		*															
		16	0.7	*	*	*			*										
		8	2	26	19	7	2		21	5	2	1	7	2	4		2		2
		4	3	25	33	5	1	1	20	3	1	1	3	1	2	2	1		1
		2	4	18	27	8	+	2	25	3	1	+	4		+	9	3	+	
1274	CC	16	0.6	*	*	*			*					*					
		8	1	14	14	25	3		28	5	2		1	2	2	1	1		2
		4	3	17	10	12	5	2	47	2	+			1	1	2	1		+
		2	3	23	21	10	4	4	27	2	2				2	3	2	+	
Fairview																			
P-1316	B	16	0.5						*					*					*
		8	0.8			30			54	1	1		1	1	1	3			8
		4	0.9			40			36	3				2		16			3
		2	1			51			31	2			2			11			3
1315	CL	16	0.5		*				*		*			*					
		8	1			47	1		41	3	1		3	2		2			
		4	1			43	1		32	4	1		1			15			3
		2	1			43			33	2	2		2			17			1
1314	CC	38		*	*														
		16	7	59	9	14			16		2								
		8	4	44	21	10			8	3	3			4		6			1
		4	4	42	17	20			12	1			1	2		4	1		
		2	4	26	14	21			14	4	2	1	4			5	8	1	
Fort Madison																			
P-1291	G	4	0.1						46							52	2		
		2	0.1						18	1				1		66	13		1
1290	G	16	0.1							*									
		8	+	*						*	*	*				*			
		4	0.2	9		3			28	13	1	+	2	+	1	32	10	1	
		2	0.3	4		1			10	9	+		+			47	28	1	

TABLE 3 — CONTINUED

Sample no.	Zone	Fraction mm	Fraction % by wt.	Limestone	Dolomite	Sandstone, Siltstone	Shale gray, green	Shale black	Chert	Granite, Syenite	Diorite, Peridotite	Felsite	Basalt, Greenstone	Quartzite	Schist, Gneiss	Quartz	Feldspar	Hornblende, Augite	Others
Fort Madison (continued)																			
1289	CL	16	0.4	*		*				*			*						
		8	0.9	24		17			11	22	6	1	11	3	2	3			
		4	1	11		11			10	22	3	2	18	1	6	10	3	1	2
		2	1	5		2			5	17		1	18		1	22	28	1	
1288	CC	16	0.2							*				*					
		8	0.8	44	2	8			13	7	6	3	8		4	1			4
		4	1	26	4	6			7	19	5	3	11		2	11	4		2
		2	2	21	2	5			5	23	6	1	10		3	12	12		+
Funkhouser																			
P-1287	B	38									*								
		16	0.8			*			*	*			*						
		8	1			11			66	4	4	1	5	4	1	4			
		4	2			22			57	7	4		4	1		5			
		2	2			17			54	4	2					13	10		
1324	B	38				*													
		16	0.6			*			*	*				*					
		8	0.9			18			62	4	2	2	2	3	3	4			
		4	2			31			44	7	1	1	2	2		11			1
		2	2			34			30	11			1	1		16	6		1
1323	CL	16	0.9	*		*			*	*	*		*	*					
		8	1	1	1	24	+		50	9	3	+	4	5	1	1	1		+
		4	2	2		33			37	4	3		2	4		14	1		
		2	2			30		+	34	3	3		4	1		18	7		
1286	CC	16	0.7	*	*	*				*					*				
		8	2	23	34	11			16	5	1		5	4	1				
		4	3	22	23	17		1	23	2	1	1	7			3			
		2	4	17	19	17		1	24	1	1		4	1		7	7	1	+
1322	CC	38																	
		16	0.3	*	*					*			*						
		8	2	18	13	28		1	26	2	2		2	6		2			
		4	3	22	18	22		1	21	6	1		2	2	1	1			3
		2	4	29	17	20			17	2	2		1	1	1	5	4		1
Hipple																			
P-1320	G	16	0.4			*			*	*				*					
		8	0.4			5			68		5	2		5		15			
		4	1			4			49	1		1				41	2		2
		2	1			2			53	2			1			36	6		
1319	G	38									*								
		16	3			10			74		2		2	12					
		8	4			5			61	4	4	1	1	5	1	17	1		
		4	4						64	2	+	2	2	2		28	+		+
		2	3			2			54	1			3			38	2		
1318	CL	16	0.6	*		*			*							*			
		8	1	+	2	34	3		44	4	2	1	1	3		6			
		4	2	4	8	38	3	1	25	1	2	1	2			15			
		2	1	+	3	38	3		24	2	3	+	2	1		22	2		+
1317	CC	38			*														
		16	3	32	24	26			12		3		3						
		8	3	45	14	23			10	1	3			2		1			1
		4	3	30	5	32			21	1	1		2			6			2
		2	3	34	18	21			11	1	1		1			7	4		2

* Less than 25 pebbles in fraction and percent not calculated.
\+ Less than 0.5 percent.

TABLE 4 — MINERAL ANALYSES OF SAND FRACTIONS

Sample no.	Zone	Fraction mm	Fraction percent	% Heavy minerals in fraction	Heavy Minerals (percent)																		Light Minerals (percent)						% − 2mm frac. soluble in HCl	Fraction mm	Sample no.
					Opaque		Transparent	Transparent (percent)																							
					Black	Others		Tourmaline	Zircon	Garnet	Epidote	Rutile	Kyanite	Staurolite	Andalusite	Sillimanite	Actinolite	Hornblende	Enstatite	Hypersthene	Diopside, Augite	Others	Quartz	K felds.	Na-Ca felds.	Chert	Shale	Others			
Donnellson																															
P-1301	B	.500	2																				91	3	4	-	-	2	15	.500	P-1301
		.250	5	0.30	6	72	22	8		17	19	2		13				33				8	90	5	5	+	-	+		.250	
		.125	5	0.44	12	46	42	5	2	17	28	1	1	10				34		2			84	6	6	1	-	3		.125	
		.062	3	0.76	32	25	53	5	15	9	33			10				26				2	81	9	8	1	+	1		.062	
1300	B	.500	5																				70	7	13	1	1	8	12	.500	1300
		.250	11	0.56	15	48	37	3		21	14		2	4				51	1	2		2	83	9	7	+	+	1		.250	
		.125	12	0.75	25	25	50	6		18	29		1	4				42					77	10	11	1	-	1		.125	
		.062	10	0.97	21	30	49	1	7	18	41			1				31		1			81	12	5	-	-	2		.062	
1299	CL	.500	13																				70	8	5	+	+	17	9	.500	1299
		.250	14	0.99	5	58	47	1		5	8		1	1				78		1	3	2	80	8	6	+	+	6		.250	
		.125	6	1.31	11	35	54	1	1	14	10			1				66	2		1	4	79	9	8	+	-	4		.125	
		.062	2	1.64	26	21	53	2	5	12	18				1			55	4			3	76	10	12	-	-	2		.062	
1298	CC	.500	6																				74	6	5	+	+	15	15	.500	1298
		.250	13	0.97	3	55	42			12	10			1				67	1	1	2	6	86	4	2	+	-	8		.250	
		.125	11	1.36	11	39	50		1	11	16							70				2	74	8	9	3	+	6		.125	
		.062	8	1.86	21	19	60		8	6	27	1			1		1	52	1			3	77	11	9	1	-	2		.062	
Effingham																															
P-1279	G	.500	2																				77	5	5	3	+	10	12	.500	P-1279
		.250	8	0.08	6	31	63	1		57	7						1	30	2	1		1	84	5	9	2	-	-		.250	
		.125	17	0.44	5	11	84	1	2	40	11						1	39	2	1		3	79	14	4	1	-	2		.125	
		.062	8	1.18	18	10	72	2	3	52	16		1					21				5	69	11	18	1	-	1		.062	
1278	G	.500	3																				81	5	9	4	+	1	9	.500	1278
		.250	19	0.29	7	12	81	1	1	42	12						1	39	2			2	85	8	7	-	-	+		.250	
		.125	19	0.56	7	11	82	1	4	27	12						2	51	2			1	82	15	2	-	-	1		.125	
		.062	9	1.73	25	9	66	1	7	45	18		1					28					76	19	4	+	-	1		.062	
1277	G	.500	4																				74	8	14	2	-	2	8	.500	1277
		.250	16	0.32	10	19	71			26	6				1			60	2	2		3	80	16	2	+	-	2		.250	
		.125	20	0.76	10	9	81	2	1	13	12				2			66				4	70	16	12	1	-	1		.125	
		.062	11	1.50	20	8	72	2	5	32	15				1			42	1	1		1	75	17	6	+	+	2		.062	
1276	CC	.500	8																				55	8	13	4	3	17	20	.500	1276
		.250	17	1.76		86	14			21								79					70	12	4	+	+	14		.250	
		.125	10	2.06	2	48	50			18	6						1	70	1		1	3	70	12	10	1	+	7		.125	
		.062	8	3.44	4	50	46	2	1	12	12	1					1	62	2	1		6	63	19	9	2	+	7		.062	
1275	CC	.500	6																				28	7	7	2	2	54	26	.500	1275
		.250	10	1.62	1	68	31			13	4						1	69	1	5	3	4	69	6	9	2	+	14		.250	
		.125	10	2.11	14	35	51	1		22	5						4	61		6	1		69	18	4	+	+	9		.125	
		.062	8	2.40	27	23	50		1	26	11			1				56			3	1	74	10	13	-	+	3		.062	
1274	CC	.500	6																				29	9	10	1	2	49	25	.500	1274
		.250	12	1.54	2	59	39	2		15	1							71	3	4	2	2	70	16	3	1	1	9		.250	
		.125	10	1.78	5	38	57		1	10	3							74	1	3	5	3	72	11	13	3	+	1		.125	
		.062	8	3.08	9	21	70	1	3	18	7	1					1	65		3	1		74	18	2	+	1	5		.062	

TABLE 4 — Continued

Sample no.	Zone	Fraction mm	Fraction percent	% Heavy minerals in fraction	Heavy Minerals (percent): Opaque: Black	Heavy Minerals (percent): Opaque: Others	Heavy Minerals (percent): Transparent	Transparent (percent): Tourmaline	Zircon	Garnet	Epidote	Rutile	Kyanite	Staurolite	Andalusite	Sillimanite	Actinolite	Hornblende	Enstatite	Hypersthene	Diopside, Augite	Others	Light Minerals (percent): Quartz	K felds.	Na-Ca felds.	Chert	Shale	Others	% – 2mm frac. soluble in HCl	Fraction mm	Sample no.
Fairview																															
P-1316	B	.500	2																				35	2	3	1	+	59	16	.500	P-1316
		.250	6	1.19	1	71	28	3		20	6		1	1				66		3			75	8	3	+	3	11		.250	
		.125	5	1.15	1	60	39			15	20							61		2		2	77	13	5	1	-	4		.125	
		.062	5	0.55	20	37	43	2	11	25	29		1	1				31					77	9	8	+	+	6		.062	
1315	CL	.500	3																				40	2	9	1	1	46	15	.500	1315
		.250	7	2.67		90	10				5							85		5		5	72	12	3	+	+	13		.250	
		.125	6	4.67	1	64	35	1		7	6			3				79				4	78	10	5	1	-	6		.125	
		.062	7	1.52	8	54	38	4	2	11	18			2				56				7	77	9	7	-	+	7		.062	
1314	CC	.500	4																				17	2	3	2	-	76	23	.500	1314
		.250	8	2.10	1	90	9	5		20	5							70					55	5	1	-	1	38		.250	
		.125	8	2.20	3	58	39	2	1	18	13							59				7	63	10	10	2	+	15		.125	
		.062	8	0.92	18	46	36	3	13	26	19							36			1	2	74	8	12	1	+	5		.062	
Fort Madison																															
P-1291	G	.500	2																				91	3	4	+	+	2	17	.500	P-1291
		.250	4	Tr	7	57	36	6		36	21		1	20				13		3			90	5	3	+	-	2		.250	
		.125	4	0.35	14	41	45	5	2	24	39		1	6			1	19				3	85	6	6	+	-	3		.125	
		.062	3	0.65	23	29	48	8	22	8	45	1	1					13				2	80	10	7	1	-	2		.062	
1290	G	.500	5																				81	7	8	1	-	3	11	.500	1290
		.250	10	0.17	7	41	52	1		31	26		1	3				33		4	1		79	8	11	2	-	-		.250	
		.125	9	0.49	12	28	60	3		26	31	1	2	2				32		2		1	77	12	11	+	-	-		.125	
		.062	8	0.77	15	21	64	3	13	19	33							26	2			4	82	5	9	2	+	2		.062	
1289	CL	.500	8																				74	9	12	2	+	3	10	.500	1289
		.250	15	0.78	6	53	41	3		19	8			2				64	1			3	74	8	10	1	+	7		.250	
		.125	12	1.09	22	29	49	1	1	14	19	2						57				6	80	11	7	1	-	1		.125	
		.062	10	1.43	28	25	47	1	7	14	21			2	1			44	1			9	73	12	13	+	+	2		.062	
1288	CC	.500	8																				68	9	15	2	-	6	16	.500	1288
		.250	13	0.88	6	53	41	2		8	8		1	2				73		5		1	79	7	7	+	+	7		.250	
		.125	12	1.42	17	29	54	2		19	5		1	2	1			66		1	1	2	81	10	8	+	-	1		.125	
		.062	10	1.83	18	21	61	2	5	5	24	1						55		1	1	6	77	11	10	1	-	1		.062	
Funkhouser																															
P-1287	B	.500	6																				73	7	11	4	1	4	16	.500	P-1287
		.250	11	0.41	4	53	43	2	1	29	12			1				52		3			77	12	3	+	+	8		.250	
		.125	10	0.88	18	17	65	1	2	42	13							38	1		1	2	74	12	8	1	+	5		.125	
		.062	6	1.19	29	10	61		17	36	15	1						28	2		1		70	17	6	+	+	7		.062	
1324	B	.500	4																				69	8	14	6	-	3	13	.500	1324
		.250	16	0.38	10	39	51	1		32	2			1				62			1	1	74	16	3	+	+	7		.250	
		.125	12	0.61	10	28	62	3		33	8							53			2	1	77	13	6	+	-	4		.125	
		.062	7	1.24	24	3	73	1	7	37	18							34				3	68	17	11	1	-	3		.062	
1323	CL	.500	4																				63	9	13	3	+	11	11	.500	1323
		.250	15	0.72	10	40	50	1		28	2			1			1	58		1	4	4	67	16	4	+	-	13		.250	
		.125	11	1.51	12	16	72	2	1	22	6	1					1	56				11	69	15	11	1	+	4		.125	
		.062	9	2.48	18	10	72	1	3	30	7							56				3	71	13	13	1	-	2		.062	

TABLE 4 — Continued

Sample no.	Zone	Fraction mm	Fraction percent	% Heavy minerals in fraction	Heavy Minerals (percent) Opaque Black	Opaque Others	Transparent	Transparent (percent) Tourmaline	Zircon	Garnet	Epidote	Rutile	Kyanite	Staurolite	Andalusite	Sillimanite	Actinolite	Hornblende	Enstatite	Hypersthene	Diopside, Augite	Others	Light Minerals (percent) Quartz	K felds.	Na-Ca felds.	Chert	Shale	Others	% — 2mm frac. soluble in HCl	Fraction mm	Sample no.
Funkhouser, continued																															
P-1286	CC	.500	6																				30	5	8	1	-	56	26	.500	P-1286
		.250	8	0.96	7	47	46			22	6							57	2	4	6	3	70	7	3	+	+	20		.250	
		.125	10	1.56	13	28	59			26	2							61	2	2	2	5	70	21	2	-	+	7		.125	
		.062	8	1.96	17	10	73	1	5	30	8				1		1	49			1	4	71	18	5	+	+	6		.062	
1322	CC	.500	4																				43	7	15	2	2	33	25	.500	1322
		.250	14	1.32	2	50	48	1		23	3						2	62	1	3	4	1	71	15	4	-	1	9		.250	
		.125	8	1.92	7	39	54	1		29	2							62			1	5	72	14	4	-	+	10		.125	
		.062	8	2.00	23	13	64		6	19	12		1		2		1	56		1		2	68	8	17	3	-	4		.062	
Hipple																															
P-1320	C	.500	2																				70	6	9	2	1	12	15	.500	P-1320
		.250	7	0.35	3	60	37	1		29	18							47		1		4	83	12	2	-	-	3		.250	
		.125	6	0.63	20	30	50	2	1	33	18							46					76	16	4	+	+	4		.125	
		.062	4	1.00	19	29	52	5	12	16	35							32					74	7	11	1	-	7		.062	
1319	C	.500	5																				52	4	5	+	+	39	16	.500	1319
		.250	9	4.56	48	38	14			32	23							42				3	66	9	+	+	1	24		.250	
		.125	6	4.78	44	24	32	3		21	13							57			5	1	77	9	6	+	-	8		.125	
		.062	4	3.10	43	21	36	3	2	12	23							57				3	61	14	8	2	2	13		.062	
1318	CL	.500	3																				40	3	13	4	1	39	16	.500	1318
		.250	8	1.98	10	72	18	2		22	2							72				2	68	9	2	+	3	18		.250	
		.125	6	2.08	10	52	38	4		12	14		1					63	1			5	68	14	4	+	5	9		.125	
		.062	5	1.18	24	34	42		9	27	14		1					40				9	65	14	8	3	3	7		.062	
1317	CC	.500	5																				42	4	3	2	+	49	21	.500	1317
		.250	9	1.50	1	64	35	1		8	6			1				76		3	4	1	70	7	7	2	1	13		.250	
		.125	5	1.83	4	58	38	2		12	9	1		1				65		2	2	6	67	9	9	1	4	10		.125	
		.062	5	1.08	28	30	42	1	22	20	12	1						40			1	3	69	10	11	1	2	7		.062	

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